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GAS TURBINE COMPRESSOR DEVELOPMENT PROGRAM FOR 1.5/3 KW GENERAT--ETC(U)
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U N C L A S S I F I E D

REPORT 75-311130

GAS TURBINE COMPRESSOR DEVELOPMENT PROGRAM FOR 1.5/3 KW GENERATOR SET

FINAL REPORT

BY
JESSE B. LEE
AND
DR. EUGENE A. ZANELLI

DECEMBER 1975

FOR

U.S. ARMY MOBILITY EQUIPMENT RESEARCH
AND
DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA 22060

PREPARED UNDER
CONTRACT NO. DAAK02-74-C-0167, DATA ITEM A002

BY

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
402 SOUTH 36TH STREET
PHOENIX, ARIZONA 85010

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SUMMARY

The program described herein was initiated to determine the feasibility of utilizing a simple cycle gas turbine engine capable of providing 6 hp for driving a 1.5/3 kW generator set. Specific objectives were to: (1) perform the preliminary design of a small gas turbine engine, and (2) design and test the engine compressor.

A cycle study was performed during which analysis of the engine cycle was conducted to ensure that engine performance requirements were met for specified altitude and temperature ranges. Study results indicate that by using conservative state-of-the-art values in estimating component performance, all requirements can be satisfied. The final cycle parameters are: 0.138 lb/sec corrected flow rate, 3.5:1 pressure ratio, 1920°F maximum cycle temperature,* and 140,000 rpm shaft speed.

Compressor testing demonstrated a compressor design point stage performance of 74 percent efficiency (74.6 percent peak) and 3.4:1 pressure ratio at 0.138 lb/sec airflow.

*Anticipated 1980's state-of-the-art

FOREWORD

This work was authorized under Contract DAAK02-74-C-0167 to perform initial Advanced Development efforts on components for a future gas turbine generator set in the 1.5 - 3.0 kW power range. The applicable DA Project is 1G763702DG11, Mobile Electric Power Systems.

The authors wish to acknowledge contributions made to this program by the following Garrett Corporation employees:

K. Benn, C. Linder, and K. Krieger, for assistance in program management.

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C. Bishop, for assistance in editing and preparing the final report.

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LIST OF TABLES

1. INTRODUCTION

This document summarizes a study conducted to perform preliminary design of a small gas turbine engine, and to demonstrate performance of the resultant engine compressor design. Primary concerns of the preliminary engine design were simplicity, low initial cost, ruggedness, reliability, maintainability, and long life consistent with attainable engine component performance.

Engine design parameters were established to provide an engine capable of providing 6 hp to drive a generator set of 3.0 kW net electrical output. An alternate configuration, providing 1.5 kW, was also considered in the engine design. The stated electrical outputs were based on a 0.67 overall electrical efficiency as specified by MERDC for previous work done by others.

MERDC-suggested engine design parameters were as follows:

A. Simple cycle (non regenerative)

B. Single-stage centrifugal compressor

C. Single-stage uncooled radial turbine

D. Rolling element bearings

E. Compressor pressure ratio of approximately 3.0 to 1 to 3.5 to 1

F. Compressor mass flow of approximately 0.17 lb/sec

G. Shaft speed of 140,000 rpm

The program was conducted to provide maximum use of accumulated research and development test experience on small gas turbine components, and in particular, the compressor. For example, it was possible to base compressor impeller performance predictions on test data obtained from an existing family of compressors ranging in size from 21.90 in. exit diameter and 12.5 lb/sec corrected flow, to 4.25 in. exit diameter and 0.6 lb/sec corrected flow.

This test experience is also the basis for assessing the effects of factors such as Reynolds number, clearance, and practical fabrication considerations.

Similar background also exists for other engine components, and although program scope did not require complete design in these areas, this experience formed the basis for preliminary engine design effort.

2. INVESTIGATION

The primary program objective was to conduct a development program to demonstrate adequate compressor performance for application in a 1.5 to 3 kW gas turbine-driven generator set. An additional requirement was to show how the compressor, and other engine components, would be incorporated in an overall engine and generator set design. The program consisted of investigating the areas discussed in Paragraphs 2.1 through 2.6.

2.1 CYCLE AND DESIGN STUDIES

2.1.1 Cycle Analysis

Preliminary investigation showed that with precise clearance control, an adiabatic efficiency of 78 percent could be achieved for the compressor. However, the cycle analysis provided for a more conservative value of 75 percent. A corrected mass flow of 0.138 lb/sec and a pressure ratio of 3.5:1, together with other cycle assumptions, were determined to yield the specified 6 hp with a specific fuel consumption (sfc) of 1.35 lb/hp-hr.

Original cycle assumptions at the design point are as follows:

A.	Inlet heating, °F	5
B.	Leakage, percent	1.0
C.	Inlet $\Delta P/P$	0.01
D.	Combustor $\Delta P/P$	0.05
E.	Accessory power, hp	1.25
F.	Mechanical efficiency, percent	98.5
G.	Exhaust $\Delta P/P$	0.02

These parameters were retained for off-design performance calculations, except that pressure losses were allowed to vary as a function of the square of the corrected flow. Performance calculations were made at conditions shown in Table I. Sea level, 60°F design point conditions are shown in Table II.

TABLE I. ALTITUDE AND TEMPERATURE RANGE FOR DESIGN

TEMPERATURE (°F)	ALTITUDE (FT)
-65	0
+60	0
+125	0
+107	5000
+95	8000*

*90 percent power point at 1920°F turbine inlet temperature.

TABLE II. DESIGN POINT CONDITIONS FOR SEA LEVEL 60°F	
1. Compressor Total-Total Pressure Ratio	3.5:1
2. Compressor Total-Total Adiabatic Efficiency, Percent	75
3. Turbine Efficiency, Percent	81
4. Turbine Inlet Temperature, °F	1483
5. Output Power, hp	6.0
6. Fuel Consumption, lb/hr	8.1
7. Specific Fuel Consumption, lb/hp-hr	1.35

Figure 1 shows estimated engine performance through an operating temperature range of -65 to +125°F at sea level and -65 to +107°F at 5000 ft. The engine is loaded with 6 hp for both curves. The 90-percent power point for an 8000 ft, 95°F day is also shown in Figure 1.

An analysis was made to determine performance at the 1.5 kW (3.0 hp) alternate rating. The most direct approach is a reduction of turbine temperature. However, this approach involves increased specific fuel consumption. Therefore, other options were investigated; namely, reduction in rotor speed, and reduction in turbine nozzle area. These changes force operation at a higher turbine inlet temperature and provide lower sfc. Table III shows the results of this study.

Table III shows that a speed reduction has greater effect on reducing sfc than a reduction in nozzle area. A 20,000 rpm speed reduction results in a 10 percent sfc reduction, and a combined reduction of 20,000 rpm speed and 4 percent nozzle area results in a 12 percent sfc reduction. Reducing nozzle area by 4 percent with no speed reduction drops sfc by only 2 percent.

2.2 PRELIMINARY ENGINE DESIGN

2.2.1 Rotating Group Arrangements

Conceptual layout drawings were produced to illustrate the turbo-alternator and gear driven generator designs. These drawings (SKP32440 and SKP32441) are included in Appendix I.

2.2.1.1 Turbo-Alternator Design

Critical speed and bearing load analyses of the design concept shown in Figure 2, were conducted. A constant center of gravity eccentricity of 0.0005 in. for the entire shaft length was used. The analytical model of this shaft arrangement is shown in Figure 3.

A steel impeller was used in the dynamic analysis model for this engine configuration. High temperature engine environment precluded aluminum for this design.

1. NOMINAL OUTPUT SHAFT HORSEPOWER EQUALS 6.0 (EXCEPT 8000 FT POINT, WHICH IS 5.4).
2. NOMINAL GOVERNED ROTOR SHAFT SPEED EQUALS 140,000 RPM.
3. FUEL LOWER HEATING VALUE EQUALS 18,400 BTU/LB.

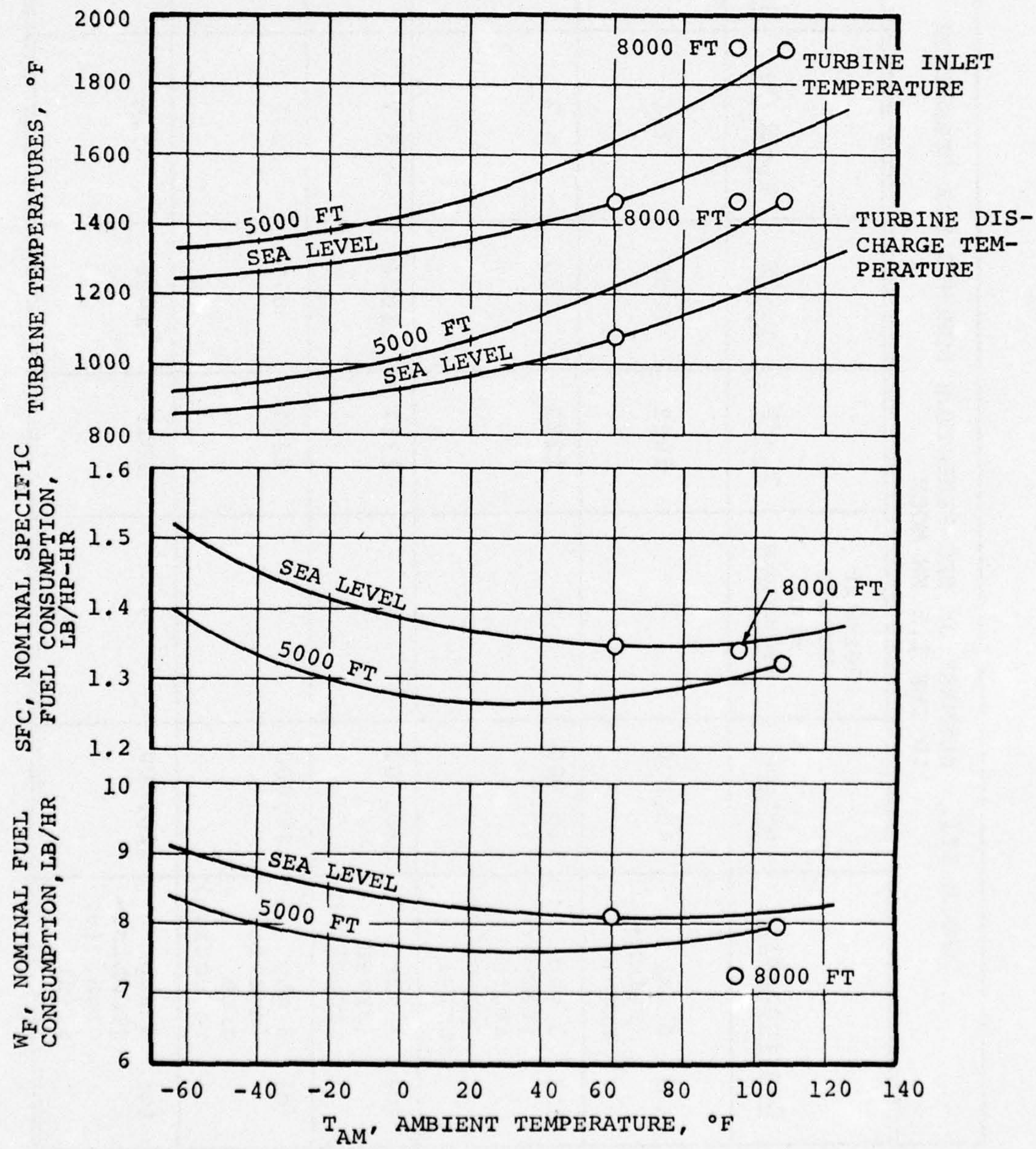


Figure 1. Estimated Performance, Model GTG3-1.

TABLE III. SUMMARY OF SFC REDUCTION SCHEMES FOR OPERATION IN THE 1.5 KW MODE

Configuration	N-rpm	Percent Nozzle Area Reduction	T_4-°F	T_5-°F	W_f-lb/hr	sfc lb/shp-hr
(a) 6 shp (reference)	140,000	0	1483	1089	8.1	1.35
(b) 3 shp (temperature reduction only)	140,000	0	1223	883	6.3	2.10
(c) 3 shp (speed reduction)	120,000	0	1317	1024	5.7	1.90
(d) 3 shp (nozzle area reduction)	140,000	4	1224	879	6.2	2.06
(e) 3 shp (combination, (c) & (d)	120,000	4	1324	1026	5.6	1.86

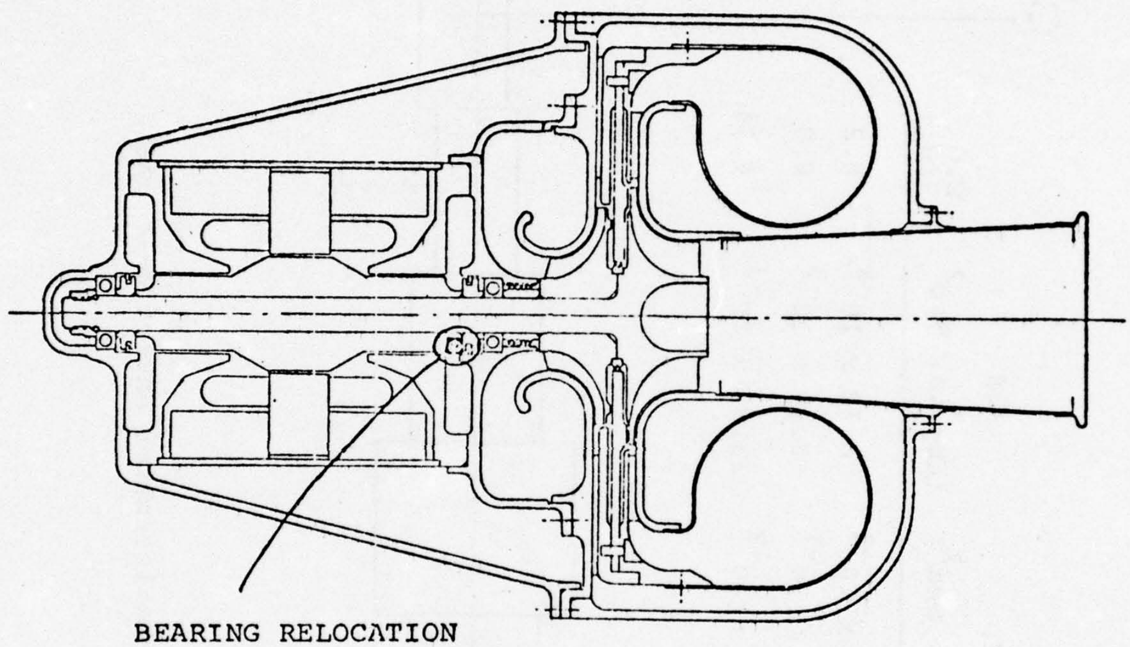


Figure 2. 1.5/3 kW Turboalternator (Drawing No. SKP32440).

	m $\frac{Lb_f\ Sec^2}{in.}$	Ip $(Lb_f\ in.\ Sec^2)$	Id $(Lb_f\ in.\ Sec^2$	C.G. (in.)
Impeller	0.81×10^{-3}	0.308×10^{-3}	0.22×10^{-3}	6.2
Turbine	1.80×10^{-3}	0.93×10^{-3}	0.69×10^{-3}	6.8
Total	5.23×10^{-3}	1.60×10^{-3}	23.85×10^{-3}	4.74

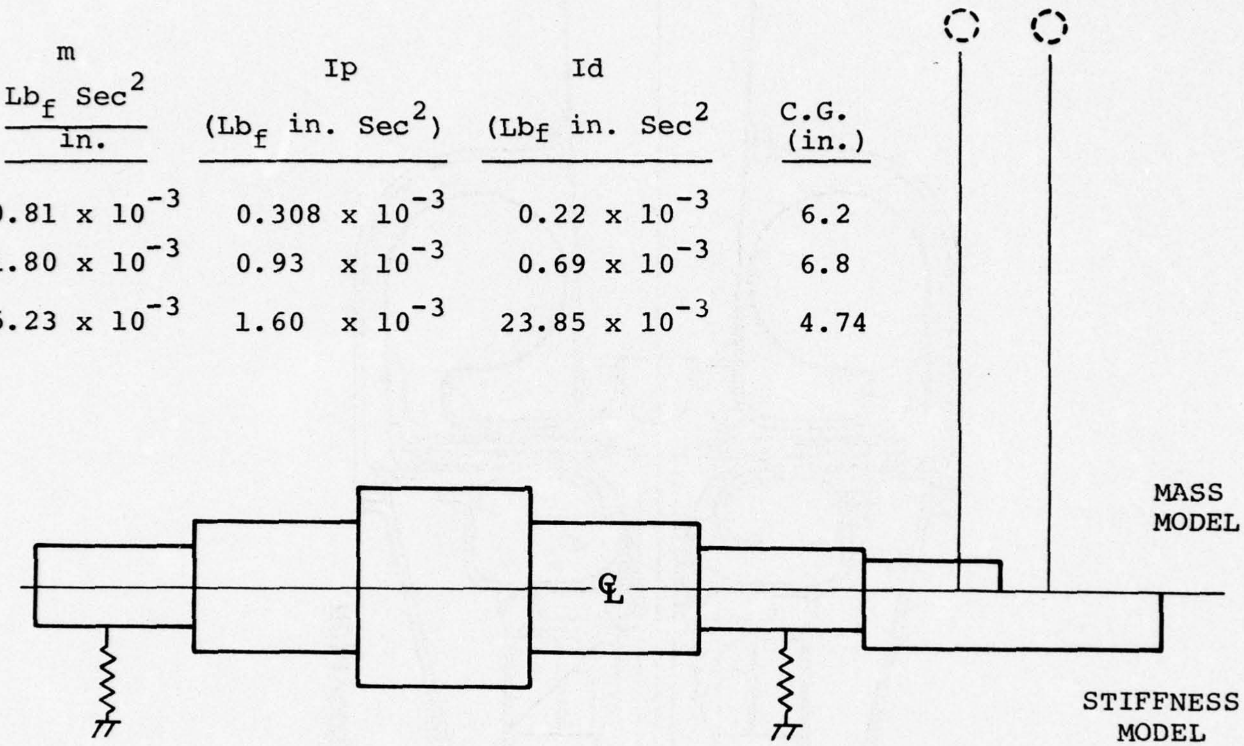


Figure 3. Turboalternator Analytical Model.

Due to unsatisfactory dynamic response and radial bearing loads, this design concept was initially considered inadequate. Table IV shows that this design has a critical speed at 140,000 rpm that coincides with the specified maximum operating speed. Also, a maximum bearing load of 5 lb radially (see Paragraph 2.2.4) is necessary to provide adequate bearing life at 140,000 rpm. Increasing the bearing spring rate, for this concept, increases the critical speed but bearing loads remain unacceptably high.

As shown in Table V, dynamic response and bearing load problems could be eliminated by doubling the shaft length between the aft end of the alternator and the forward end of the steel impeller. This would lower the basic third critical speed below the operating speed, and, while the bearing loads will also be decreased significantly, Table V also shows that both front and aft bearing spring rates of 2000 to 3000 lb/in. will be required to keep from exceeding the 5 lb bearing load limit. Lowering the third critical speed below maximum operating speed presents other problems. The third critical speed is primarily a shaft bending mode (versus the first two which are stiff shaft criticals) that requires in-place, at-speed balancing. This balancing technique is difficult, and is not recommended for a high-production, low-cost machine.

A better solution to the problem is to raise the third critical frequency above the maximum operating speed. This could be accomplished by moving the aft bearing toward the alternator (bearing relocation shown in Figure 2) thereby decreasing shaft length. This increases the third critical frequency significantly above the maximum operating speed. Table VI shows that the bearing spring rate must remain in the 2000 to 3000 lb/in. range for a maximum bearing load of 5 lb. The lower spring rate could cause a problem if a bearing bottoms-out because both the spring rate and bearing load would increase sharply, thus reducing bearing life. While the probability of bottoming-out at any speed, (other than a critical speed) is small, lower spring rates greatly increase this possibility. It should be noted that no attempt was made to combine different spring rates for the forward and aft bearings. It is dynamically feasible to build a modified version of the engine shown in Figure 2.

TABLE IV. CRITICAL SPEEDS AND BEARING LOADS FOR 1.5 KW TURBOALTERNATOR SKP32440 STEEL IMPELLER - 1 SHAFT DESIGN

Springrate lb/in	1st Critical rpm	2nd Critical rpm	3rd Critical rpm	4th Critical rpm	Front Bearing Load @ 140 KRPM (lb)	Rear Bearing Load @ 140 KRPM (lb)
5,000	8,715	21,288	140,187	565,011	2455	2054
10,000	12,090	29,694	144,367	566,387	211.2	172.5
20,000	16,477	40,939	152,569	569,132	147.7	115.7
50,000	23,570	60,829	175,687	577,322	133.8	44.1
100,000	29,068	79,981	209,372	-	149.3	98.3

TABLE V. CRITICAL SPEEDS AND BEARING LOADS FOR 1.5/3 KW TURBOALTERNATOR WITH THE DISTANCE BETWEEN AFT END OF ALTERNATOR AND FORWARD END OF STEEL IMPELLER DOUBLED

REVISION OF SKP32440

Springrate lb/in	1st Critical rpm	2nd Critical rpm	3rd Critical rpm	4th Critical rpm	Front Bearing Load @ 140 KRPM (lb)	Rear Bearing Load @ 140 KRPM (lb)
1,000	3,239	9,144	85,039	418,738	1.9	1.8
2,000	4,526	12,880	86,340	418,968	3.9	3.5
5,000	6,911	20,142	90,177	419,657	10.2	9.3
10,000	9,263	28,025	96,343	420,803	22.7	20.5
20,000	11,922	38,597	107,859	423,088	58.8	52.0
50,000	15,259	57,904	137,244	429,875	1000.	1000.
100,000	17,151	77,614	175,476	440,930	221.5	187.0

TABLE VI. CRITICAL SPEEDS AND BEARING LOADS FOR 1.5/3 KW TURBOALTERNATOR WITH AFT BEARING MOVED FORWARD TO THE ALTERNATOR AND WITH SHAFT LENGTH REDUCED BY THAT SAME AMOUNT

REVISION OF SKP32440 (STEEL IMPELLER)

Springrate lb/in	1st Critical rpm	2nd Critical rpm	3rd Critical rpm	4th Critical rpm	Front Bearing Load @ 140 KRPM (lb)	Rear Bearing Load @ 140 KRPM (lb)
1,000	3,825	10,100	181,582	604,465	2.5	1.7
2,000	5,397	14,256	182,269	604,500	4.8 *	3.4
5,000	8,473	22,415	184,323	604,603	11.7	8.1
10,000	11,843	31,412	187,730	604,777	22.1	14.9
20,000	16,373	43,655	194,475	605,119	40.2	25.6
50,000	24,282	65,897	214,036	606,124	82.9	46.6
100,000	31,260	87,650	244,115	607,714	146.0	76.5

*Both front and rear bearing loads are increasing with increasing speed for all springrates. Therefore all overspeeding above 140 KRPM causes even higher bearing loads.

2.2.1.2 Engine with Gearbox Design

Critical speed and bearing load analyses of the engine with gearbox design, were conducted. This design concept is shown in Figure 4. In this design, the impeller is removed from proximity to the turbine and may be fabricated from aluminum. The shafting analysis was performed on a 3-beam system comprised of the main shaft, quill shaft, and the short gear shaft that drives the gear train. Figure 5 shows the analytical model of this configuration. Results of critical speed and bearing load analyses (Table VII) show that a 5 lb radial bearing load would be achieved with a bearing spring rate slightly greater than 5000 lb/in. The quill shaft shown has a critical frequency at 105,000 rpm as shown in Table VII. This critical speed may be raised out of the operating speed range by reducing quill shaft length by 30 percent.

2.2.2 Turbine Design

Turbine geometry was defined to the extent necessary to derive a complete engine concept. Figure 6 shows the resultant turbine flow path.

Stator solidity will ultimately depend on the total turning required and the manufacturing limitations imposed on stator trailing edge thickness. Rotor geometry is based on specifying a blade-speed to ideal jet speed (F_V) of 1.0 and an exit Mach number of 0.250. Theoretically, the F_V versus efficiency curve is a parabola with the maximum efficiency occurring at $F_V = 1.0$. Actual turbine test data has shown the same parabolic trend at reduced efficiency levels. Although low exit Mach number results in relatively high rotor turning, rotor tip clearance effects are significantly reduced due to increased rotor exit blade height. A 2:1 area ratio conical exhaust diffuser, with a diffuser recovery of 0.50, was assumed for the engine configuration.

2.2.3 Combustor Design

Combustor design effort was confined to a preliminary sizing analysis necessary to establish overall engine envelope. However, the combustor sizing analysis, at design point conditions noted below, indicated that the

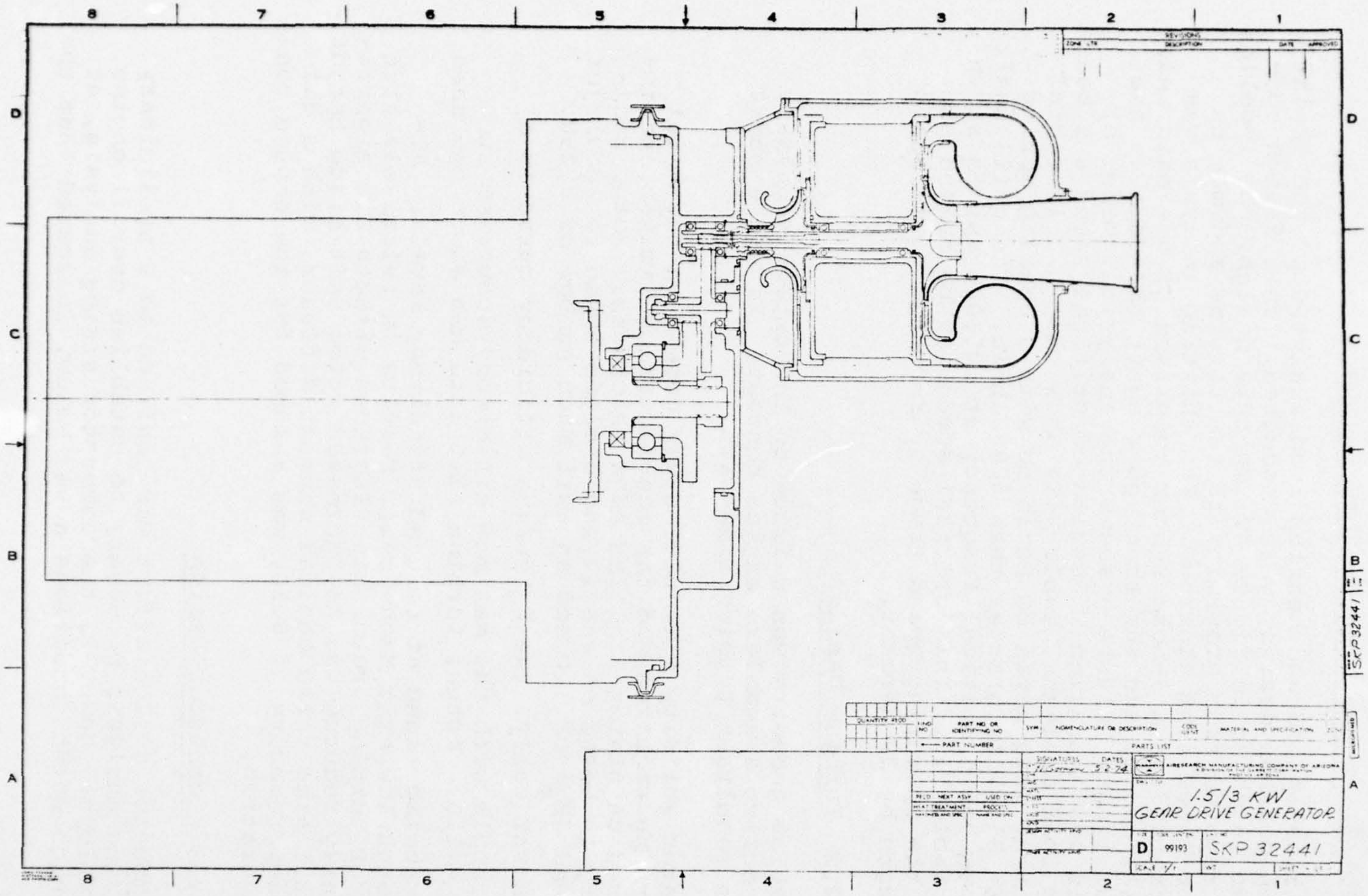


Figure 4. 1.5/3 kW Gear Drive Generator (Drawing No. SKP32441).

	m $\frac{Lb_f\ Sec^2}{in.}$	Ip (Lb_f in. Sec^2)	Id (Lb_f in. Sec^2)	C.G. (in.)
Impeller	0.283×10^{-3}	0.108×10^{-3}	0.077×10^{-3}	2.95
Turbine	1.80×10^{-3}	0.93×10^{-3}	0.69×10^{-3}	6.4
Total	2.80×10^{-3}	1.06×10^{-3}	6.25×10^{-3}	5.27

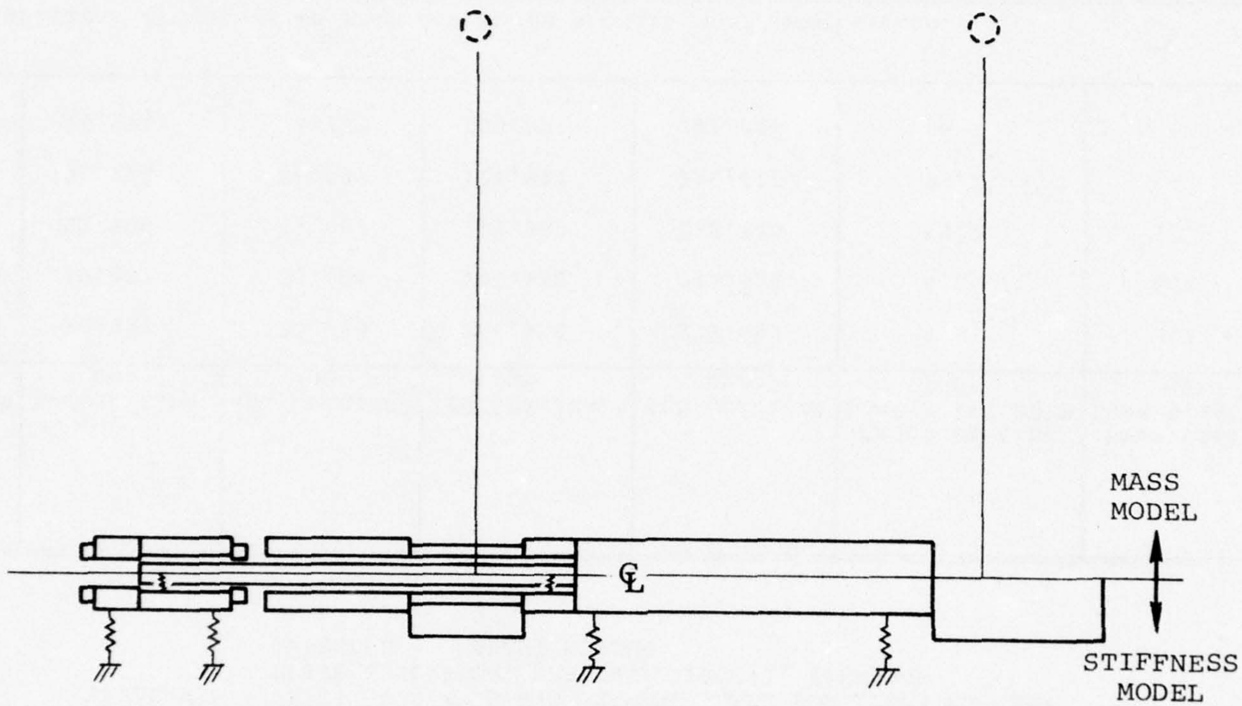


Figure 5. Gear Drive Generator Analytical Model.

TABLE VII. CRITICAL SPEEDS AND BEARING LOADS FOR 1.5/3 KW GEAR DRIVE GENERATOR, DRAWING SKP32441, ALUMINUM IMPELLER - 3 SHAFT DESIGN

Springrate lb/in	1st Critical rpm	2nd Critical rpm	3rd Critical* rpm	4th Critical rpm	Front Bearing Load @ 140 KRPM (lb)	Rear Bearing Load @ 140 KRPM (lb)
5,000	10,938	22,033	104,956	229,693	4.1	3.4
10,000	15,427	30,654	104,960	232,626	8.0	6.6
20,000	21,700	42,002	104,969	238,440	15.2	12.9
50,000	33,773	60,893	104,997	255,421	33.2	-
100,000	46,574	76,230	105,051	281,806	-	-

*The 3rd critical frequency in this design is a quill shaft excitation.

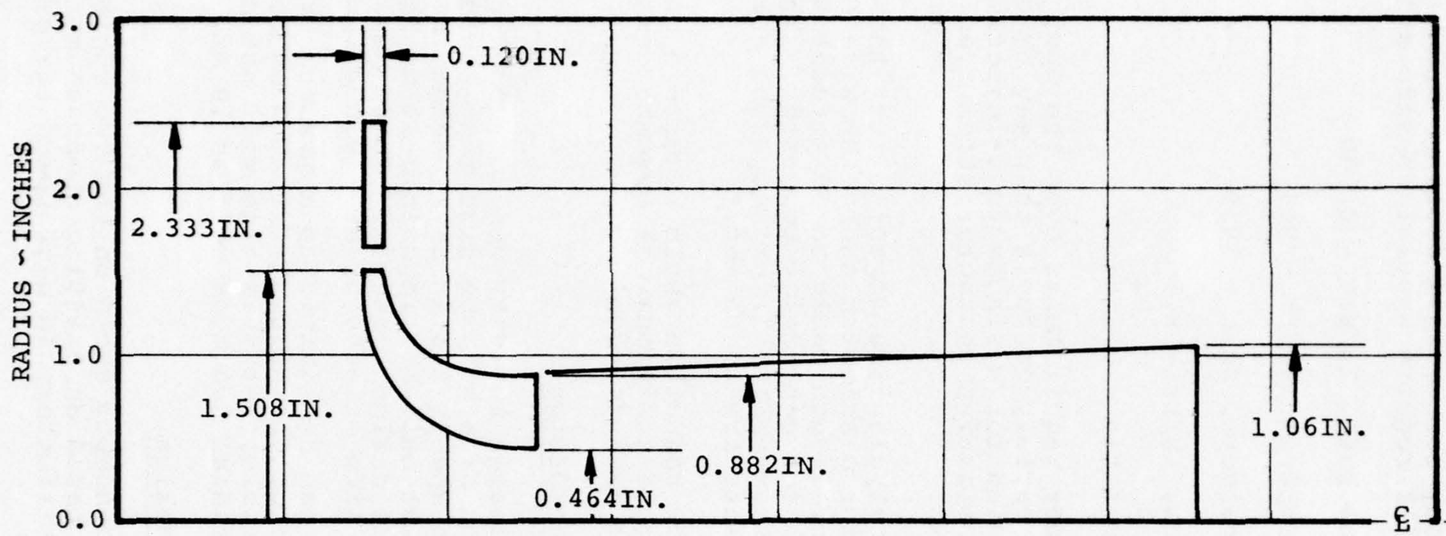


Figure 6. Turbine Design Dimensions For N = 140,000 rpm.

fuel injection, burner-wall cooling, and manufacturing tolerances will require special considerations.

Mass flow rate, lb/sec - 0.138

Inlet temperature, °F - 364

Inlet pressure, psia - 50.9

Fuel flow, lb/hr - 8.1

Fuel/air ratio - 0.0167

High efficiency requirements over the operational range, and use of a variety of fuels that may be contaminated, dictate the need for a single fuel-injection device with good atomization characteristics over a reasonable turndown ratio.

The sizing analysis also revealed that the cooling air requirement for a selected combustor size of 2 in. diameter and 4 in. length would be 59 percent of the total combustor air for a metallic combustor. This is considered to be excessive if primary zone and dilution air requirements are to be met.

A cooling flow reduction would require a zirconium oxide coating as a minimum. A ceramic combustor would eliminate the need for cooling.

2.2.4 Bearing Design

The bearing design activity was concerned primarily with selection of a bearing size that would be compatible with the speeds and loads expected in the engine. Angular contact ball bearings in a 10 mm bore are shown on both engine design concepts. These bearings should provide a B_1 life of 6000 hr at 140,000 rpm, if the radial loads can be limited to a maximum of 5 lb. Space considerations suggested that 8 mm bearings might be more desirable, but this size will not carry the anticipated radial loads as well as 10 mm.

2.2.5 Seal Design

Seal design concepts shown on the two engine design drawings are based on existing components that have performed satisfactory in high speed turbomachinery.

The turboalternator design presented in Figure 2 (Drawing SKP32440) shows rotating knife labyrinth seals between the compressor and turbine, and at the compressor inlet. This type seal has performed satisfactorily in many commercial turbomachines. The "piston ring" labyrinth seal, shown at both ends of the alternator, has been highly successful in turbochargers operating up to 130,000 rpm.

The gear drive generator concept in Figure 4 (Drawing SKP32441) shows a conventional lip seal on the low speed generator drive shaft and the two types of labyrinth seals discussed previously.

Due to limited program scope, no attempt was made to optimize seal designs for cost or reliability.

2.2.6 Alternator Design

For the turbo-alternator design, the agreed-upon Rice-type Lundell generator, designed to deliver output power through a rectifier at 28 vdc (shown in Figure 7), was used. The basic alternator characteristics are as follows:

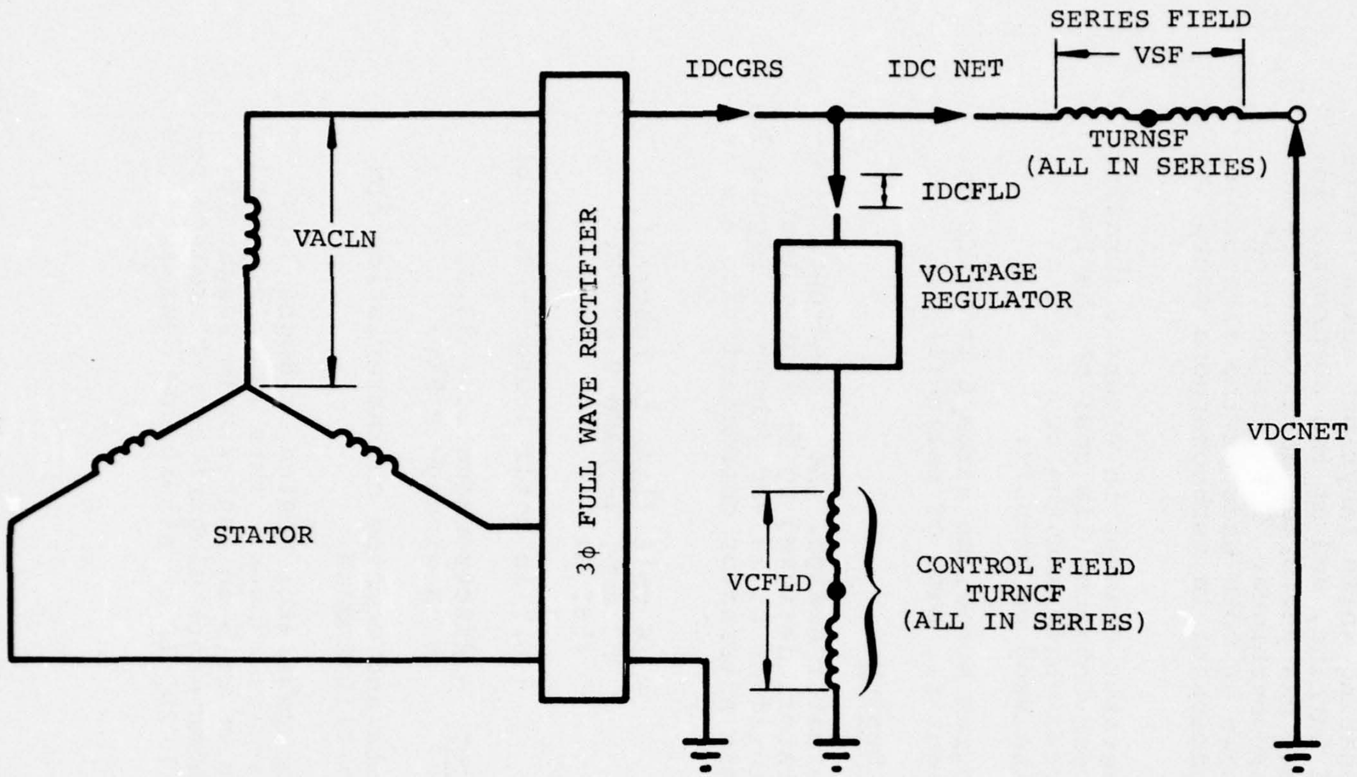
A. Rating - 16 volt (line to neutral), 82 amp, 3-phase 0.83 PF, 4667 Hz

B. Weight - 6.7 lb total (rotor - 0.7 lb)

C. Efficiency - Electromagnetic = 93.3, with windage = 91.3

Additional loss data and machine characteristics are provided on Tables VIII and IX.

For the gear driven generator design, a Bogue 3-kW 3600 rpm alternator was chosen. This is a low cost, single-bearing device with an approximate weight of 180 lb. This machine meets electrical performance requirements of the MERDC 10 kW alternator scaled to the 3 kW rating.



IDCGRS	- TOTAL DC CURRENT FROM RECTIFIER, AMPS	VDC NET	- DC BUS VOLTAGE, DC VOLTS
IDCFLD	- CONTROL FIELD CURRENT, AMPS	TURNSF	- TOTAL NUMBER OF TURNS IN SERIES FIELD
IDCNET	- DC LOAD CURRENT, AMPS	TURNCF	- TOTAL NUMBER OF TURNS IN CONTROL FIELD
VACLN	- LINE TO NEUTRAL VOLTAGE, AC VOLTS		
VCFLD	- VOLTAGE ACROSS CONTROL FIELD, DC VOLTS		
VSF	- VOLTAGE ACROSS SERIES FIELD, DC VOLTS		

Figure 7. Wiring Diagram of Turboalternator.

TABLE VIII. REACTANCE AND RESISTANCE, FIELD TIME CONSTANT		
Base Impedance	Z_{Base}	0.195 ohm
Resistances		
Armature (at 360°F)	R_A	0.0017 ohm
Reactances		
Direct Axis Synchronous	X_D	0.742 per unit
Quadrature Axis Synchronous	X_Q	0.420 per unit
Armature Leakage	X_L	0.152 per unit
Field Leakage	X_F	0.246 per unit
Zero Sequence	X_O	0.076 per unit
Negative Sequence	X_2	0.385 per unit
Transient	X_{DU}	0.398 per unit
Subtransient Direct*	$\approx X''_D$	0.350 per unit
Subtransient Quadrature*	$\approx X''_Q$	0.350 per unit
Field Time Constant (Hot)		
Short CCT	TPD	0.0198 sec
Open CCT		0.0369 sec
*Estimated value with no damper cage		

TABLE IX. ALTERNATOR AND RECTIFIER LOSSES (3 KW DC NET)	
Type	Losses (Watts)
Core	34
Teeth	50
Stator Copper	35
Stray	22
Pole Head	26
Field	65
Windage	78
Total (Alternator)	310
Efficiency (Alt)	91.3
Rectifier (Based on Loss Equivalent to 1.5 V_{FWD})	160
Total Losses	470
Efficiency (DC Net)	86.5

2.2.7 Gearing Design

A double reduction spur gear design was chosen to provide a 38.6:1 reduction to drive the 3600 rpm alternator. The gear train, shown in Figure 8, requires engine speed of 139,035 rpm at synchronous generator speed. This is approximately 0.7 percent lower than desired, but should not impose any serious problem in a final design.

2.2.8 Alternate Rating Concepts

Alternate rating concepts considered (discussed in Paragraph 2.1.1) were (1) operating at reduced temperature, (2) operating at reduced speed, (3) reducing nozzle area, and (4) combination of (2) and (3). The turbo-alternator design would be amenable to operating at reduced speed since frequency is not critical to the 28 vdc output. However, the gear driven generator set would require a gearbox change in order to operate at the reduced speed and still maintain a 60 Hz power output frequency. If lower frequency could be tolerated, the gear driven generator could also be operated at reduced speed.

No layout drawings were made to illustrate these alternate rating concepts.

2.3 COMPRESSOR DESIGN

2.3.1 Compressor Design Objective

From cycle considerations (see Section 2.1), the objective design point was established as follows:

Corrected flow ($W\sqrt{\theta}/\delta$ = 0.138 lb/sec

Total-to-total pressure ratio (PR) = 3.5

Corrected speed ($N/\sqrt{\theta}$) = 140,000 rpm

Stage efficiency (η_{ad}) = 0.75

Based on this objective design point, an existing impeller, hereinafter referred to as reference impeller (see performance maps in Figures 9 and 10), was geometrically scaled by a factor of 0.4046 and then low-flowed by incorporating a revised shroud contour. Pertinent aerodynamic and geometric parameters for the 1.5/3 kW

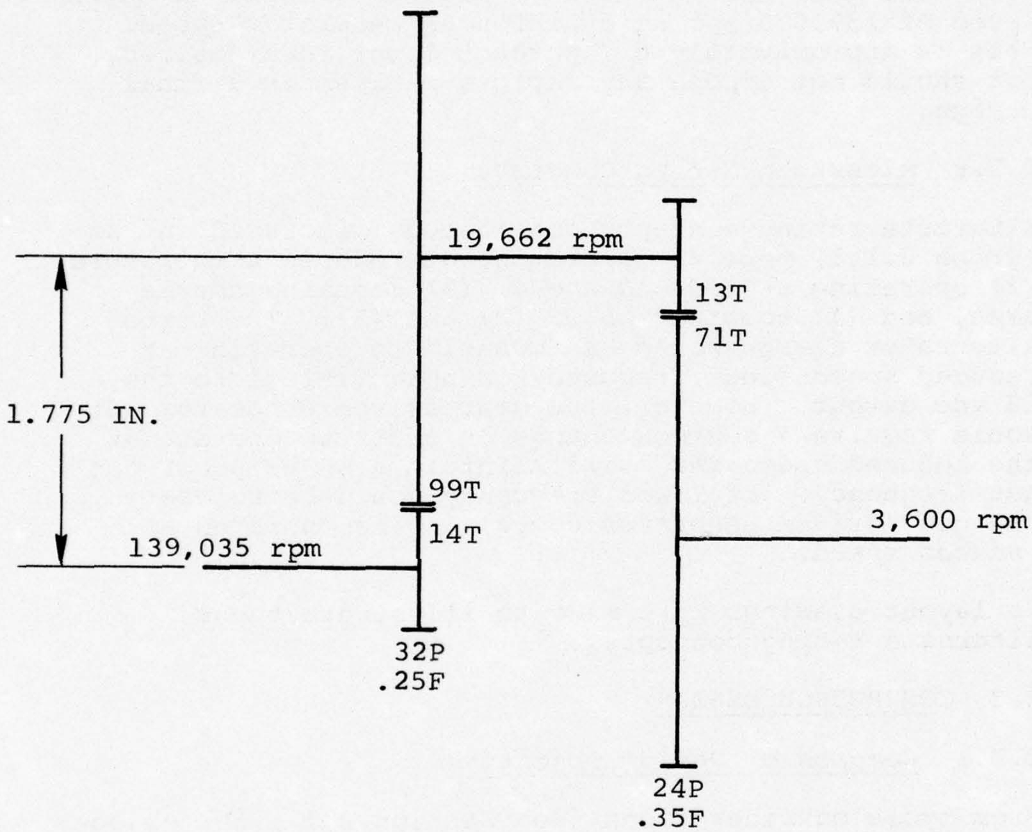


Figure 8. Gear Driven Generator Drive Train Schematic.

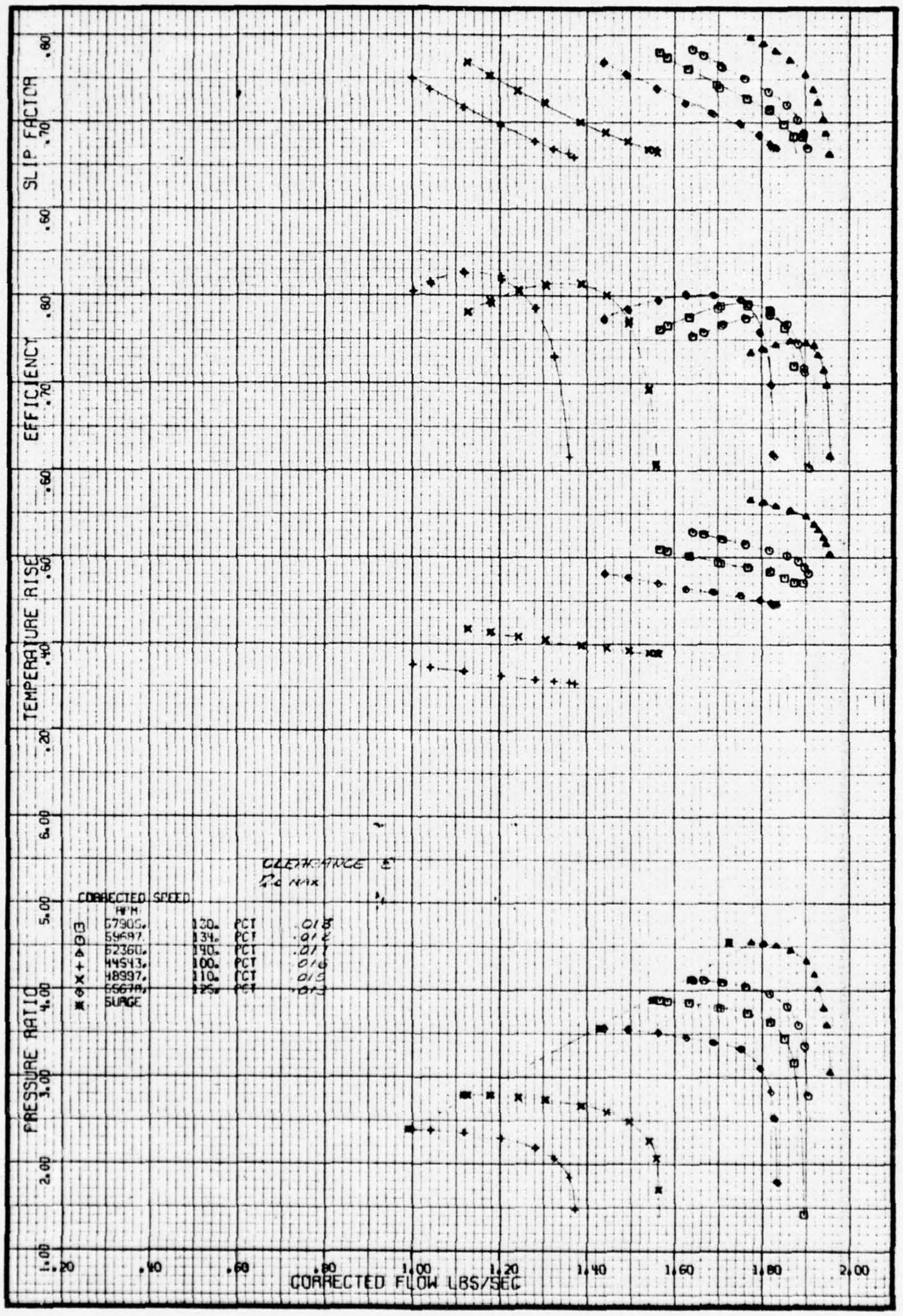


Figure 9. Reference Compressor Stage Test.

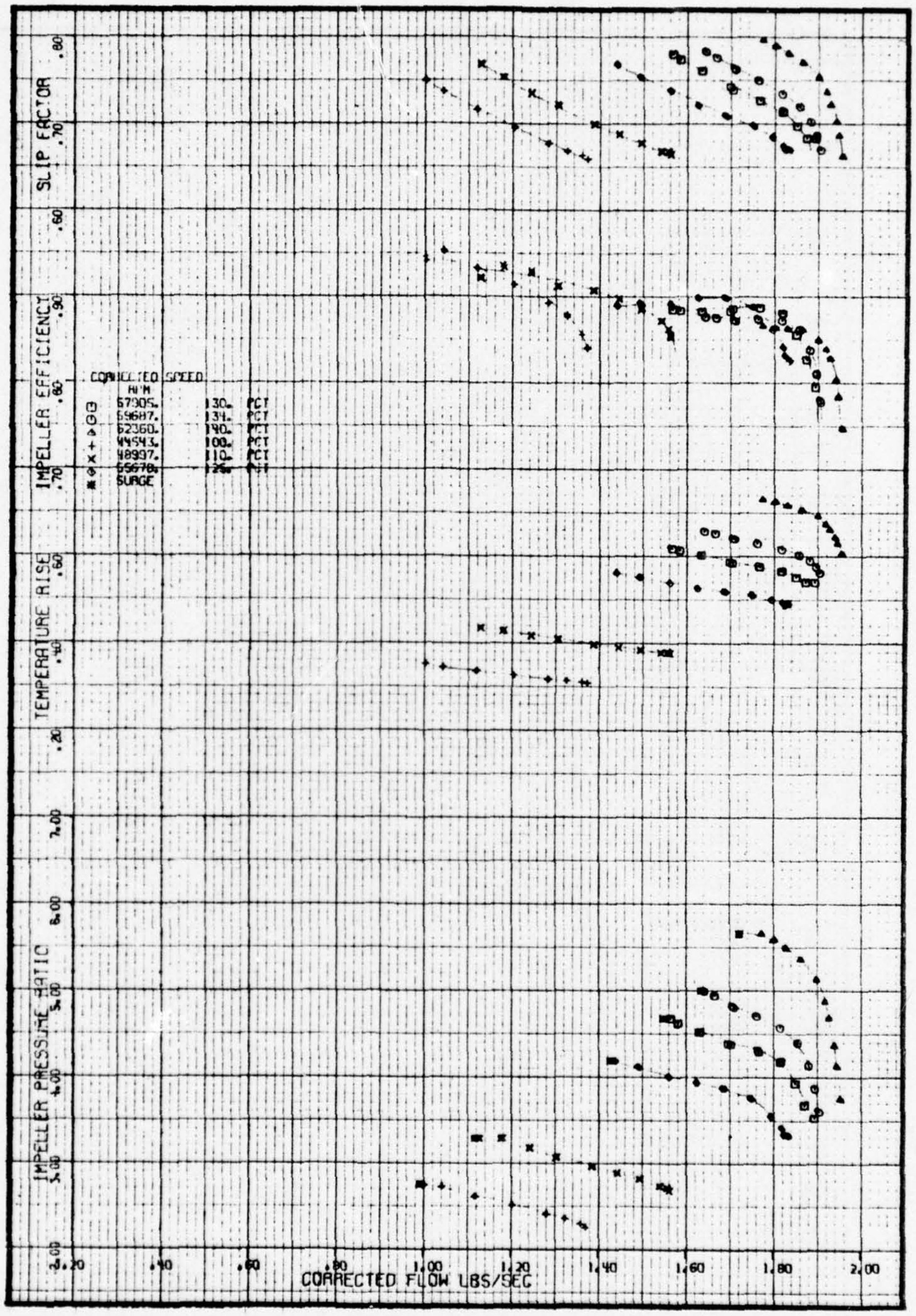


Figure 10. Reference Compressor Impeller Test.

compressor are shown in Table X. Photographs of the impeller as tested and inlet and shroud, are shown in Figures 11 and 12, respectively.

2.3.2 Impeller Considerations

Scaling the reference impeller by 0.4046 introduced the following design considerations:

A. A direct scale resulted in an unacceptably high corrected flow (nominally 0.2822 lb/sec) at design point corrected speed. To reduce corrected flow to the desired value of 0.138 lb/sec, a 51 percent flow reduction was apparently required. However, examination of the performance map for the reference compressor showed that, due to scaling effects, this compressor was 6.5 percent deficient in flow when compared to design value (also an exact geometric scale of a layer compressor). On this basis, a decision was made to reduce the compressor flow by only 40 percent from which adjustment to a lower flow could be made, if necessary by shroud recontouring after testing. The final impeller configuration is shown in Figure 13.

B. To minimize impeller machining costs, only standard size cutters were considered for impeller manufacture. This consideration limited the number of blades to fourteen instead of the fifteen blades of the reference impeller. This blade number reduction results in a slightly lower impeller exit slip factor and compressor work input than that of the reference compressor. The reduction of slip factor and compressor work was estimated to be 0.8 percent.

C. It is difficult to achieve a direct scale of impeller clearances when scaling an impeller to a smaller size. The normalized impeller clearance (ratio of shroud clearance to annulus height or width) for the impeller scaling range investigated, may be twice as large as for the parent design. This causes impeller efficiency in the smaller unit to be much more sensitive to absolute clearances than

TABLE X. MERDC 1.5/3 KW COMPRESSOR DESIGN PARAMETERS	
Stage Pressure Ratio (inlet total to diffuser exit total)	3.5:1
Stage Efficiency	75 percent
Corrected Flow	0.138 lb/sec
Corrected Speed	140,000 rpm
Specific Speed*	48.0
Number of Blades	14
Impeller Pressure Ratio (inlet total to impeller exit total)	3.925
Impeller Efficiency	0.832
Impeller Work Input ($\Delta T/T$)	0.569
Inducer Hub Radius	0.428 in.
Inducer Shroud Radius	0.675 in.
Inducer Hub Normal Thickness	0.018 in.
Inducer Shroud Normal Thickness	0.017 in.
Inducer Hub Blade Angle	59.579 deg.
Inducer Shroud Blade Angle	60.225 deg.
Inducer Tip Relative Mach No.	0.931
Impeller Axial Length	0.718 in.
Impeller Exit Tip Radius	1.263 in.
Impeller Exit Blade Width	0.072 in.
Impeller Exit Hub Normal Thickness	0.025 in.
Impeller Exit Shroud Thickness	0.023 in.
Impeller Exit Hub Blade Angle	36.726 deg.
Impeller Exit Shroud Blade Angle	38.183 deg.
Impeller Exit Absolute Mach No. (inside blade)	0.9345
Impeller Rake Angle	23.55 deg.

$$^{*}N_s = \frac{N(Q_{AV})^{1/2}}{(H_{ACT})^{3/4}}$$

N = RPM

$Q_{AV} = (Q_1 Q_2)^{1/2}$

H_{ACT} = ACTUAL ENTHALPY RISE, FT.

$Q_1 = \frac{W}{\rho})_1 \quad Q_2 = \frac{W}{\rho})_2$

1 = COMP INLET
2 = COMP EXIT
W = FLOW, LBS
ρ = TOTAL DENSITY, LB/FT^3

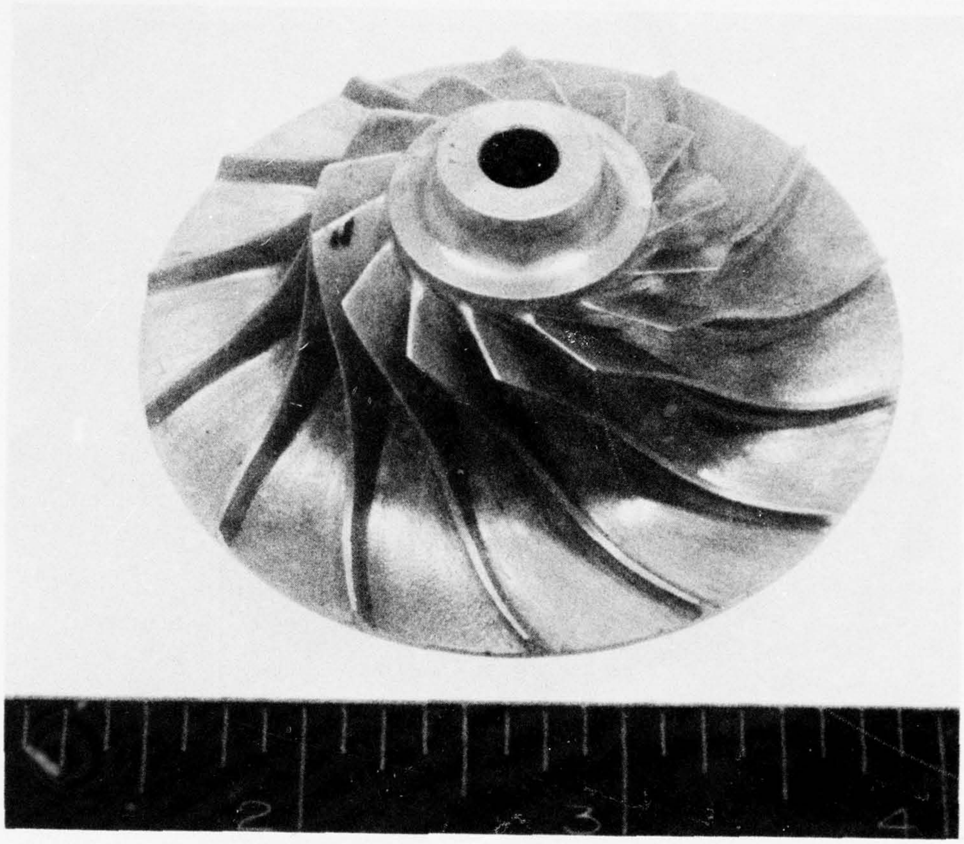


Figure 11. 1.5/3 kW Test Impeller.

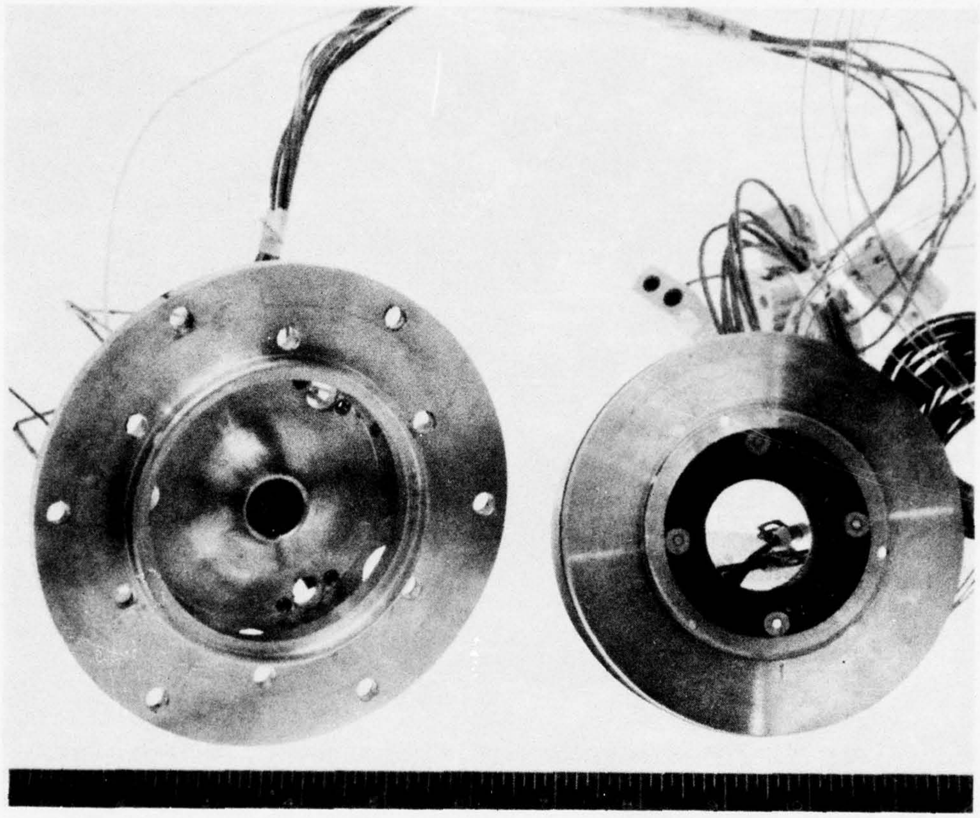


Figure 12. 1.5/3 kW Inlet Hardware.

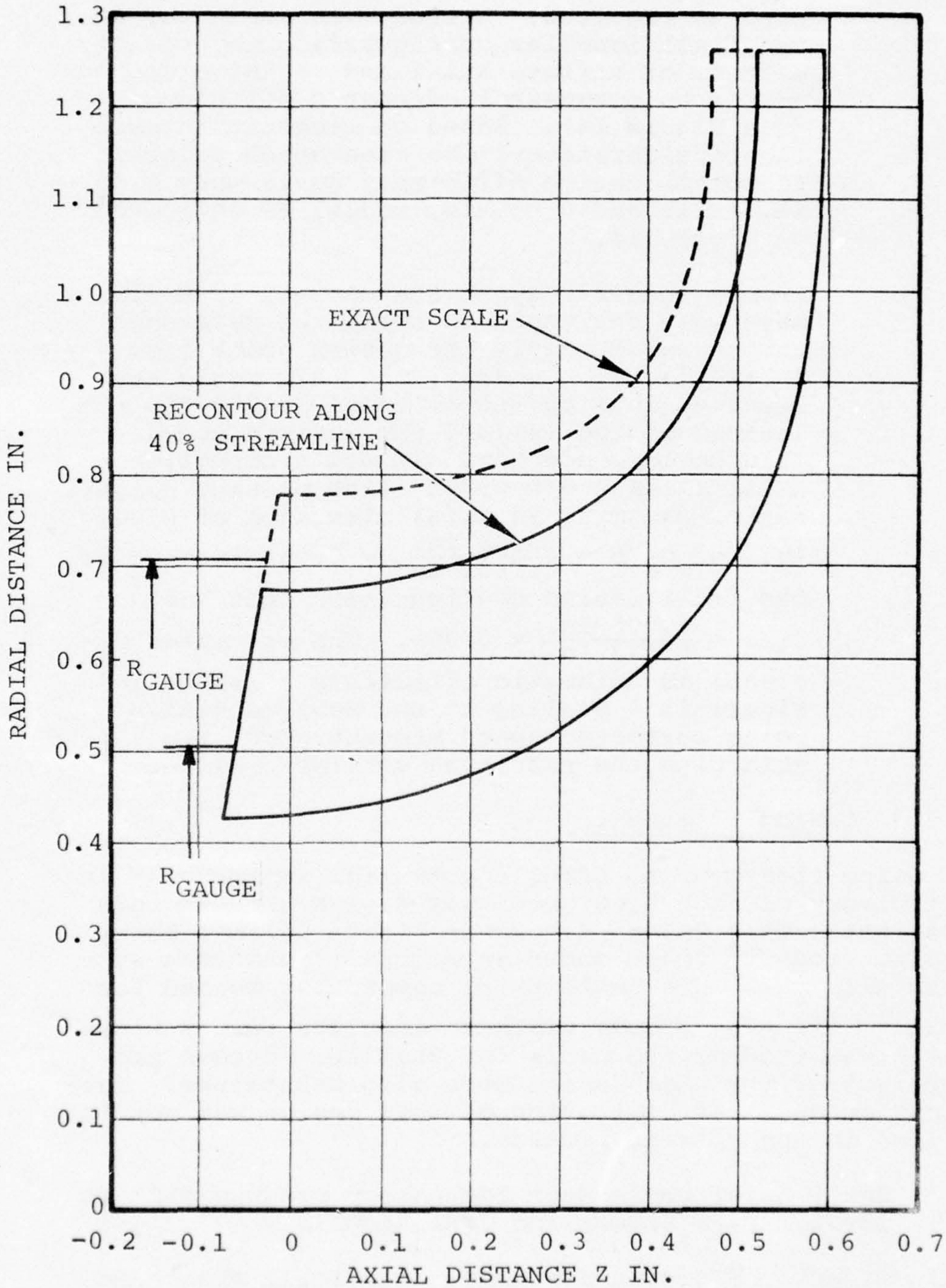


Figure 13. Impeller Meridional View.

the larger design. The sensitivity of the 1.5/3 kW impeller efficiency to clearances was further increased due to the shroud recontour required. A study was conducted on the final impeller configuration to predict effects of various axial and radial clearance values on compressor adiabatic efficiency (see Figure 14). Based on mechanical test rig considerations, the clearances selected to obtain design efficiency goals were 0.002-in. axial and 0.005-in. radial as indicated on Figure 14.

From a specific speed standpoint, it would have been desirable to scale the reference compressor strictly for design point flow (scale factor = 0.286), but this would have resulted in a corrected speed of 200,000 rpm instead of the 140,000 rpm desired speed. This scale would have allowed a normalized axial clearance/b-width (flow passage height) ratio, assuming an axial clearance of 0.005 in., of $C_a/b = \frac{0.005 \text{ in.}}{0.0858 \text{ in.}} = 0.058$ instead of the final design configuration that has a $C_a/b = \frac{0.005 \text{ in.}}{0.072 \text{ in.}} = 0.069$. The estimated decrease in adiabatic efficiency is shown in Figure 15. Scaling to the desired design point corrected speed brought about the shroud trim with the resulting smaller b-width.

2.3.3 Casing Treatment

A casing treatment to offer a potential improvement in efficiency at high clearances was designed under this contract. This design (shown in Figure 16) has been scaled from treatment shown in Figure 17 that was successfully used on a small axial compressor tested for NASA(1)(2). The groove width-to-impeller throat width ratio was used as the basis for scaling. Groove proportions of the NASA design were also maintained. Fabrication and test evaluation of this design was not included in the current program.

(1) Small Axial Compressor Technology Program NASA CR 134827, F.F. Holman and J.R. Kidwell

(2) Effects of Casing Treatment on a Small Transonic Axial Flow Compressor ASME Paper No. 75-WA/GT-5, F.F. Holman and J.R. Kidwell

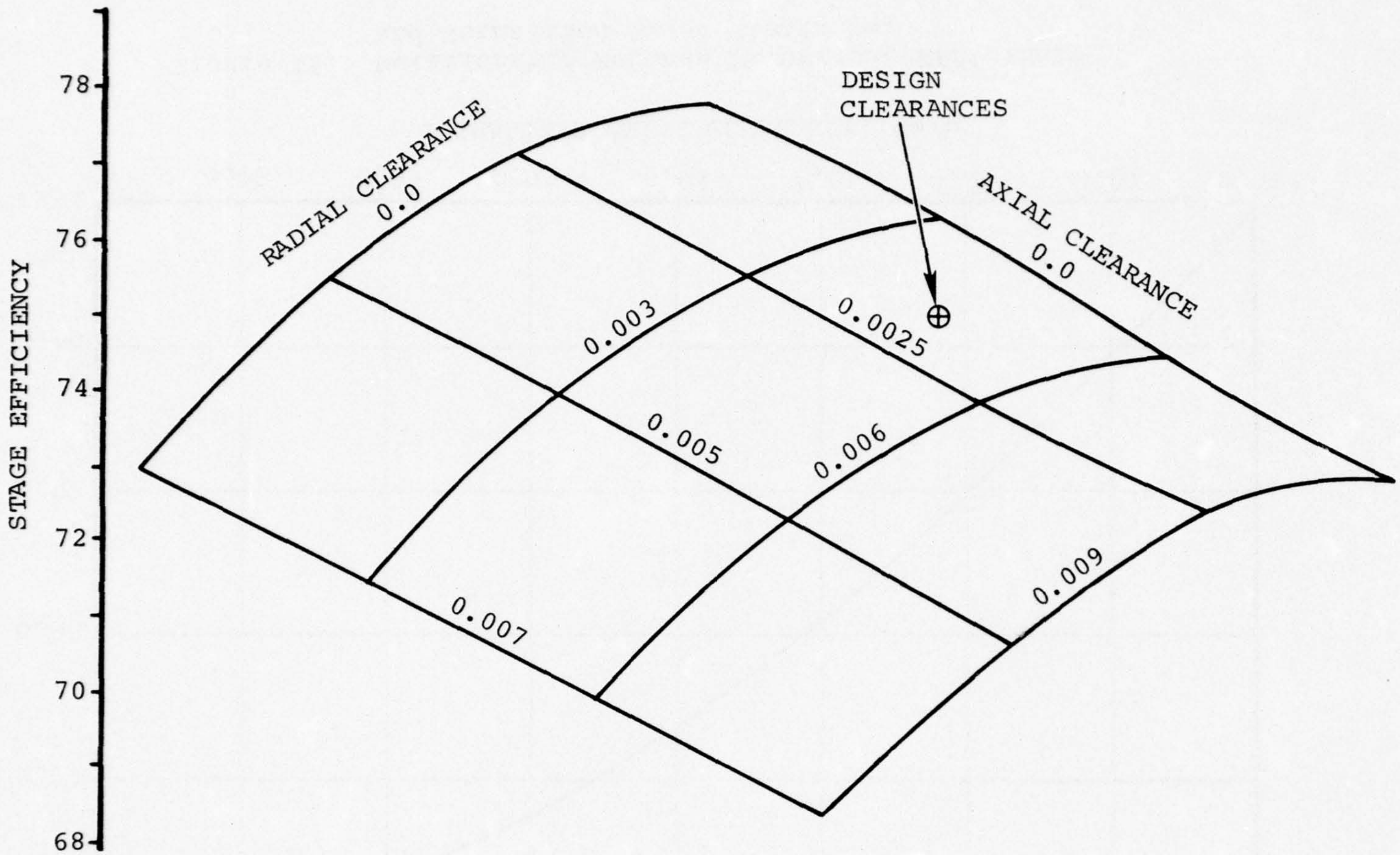


Figure 14. 3 kW Clearance Effects.

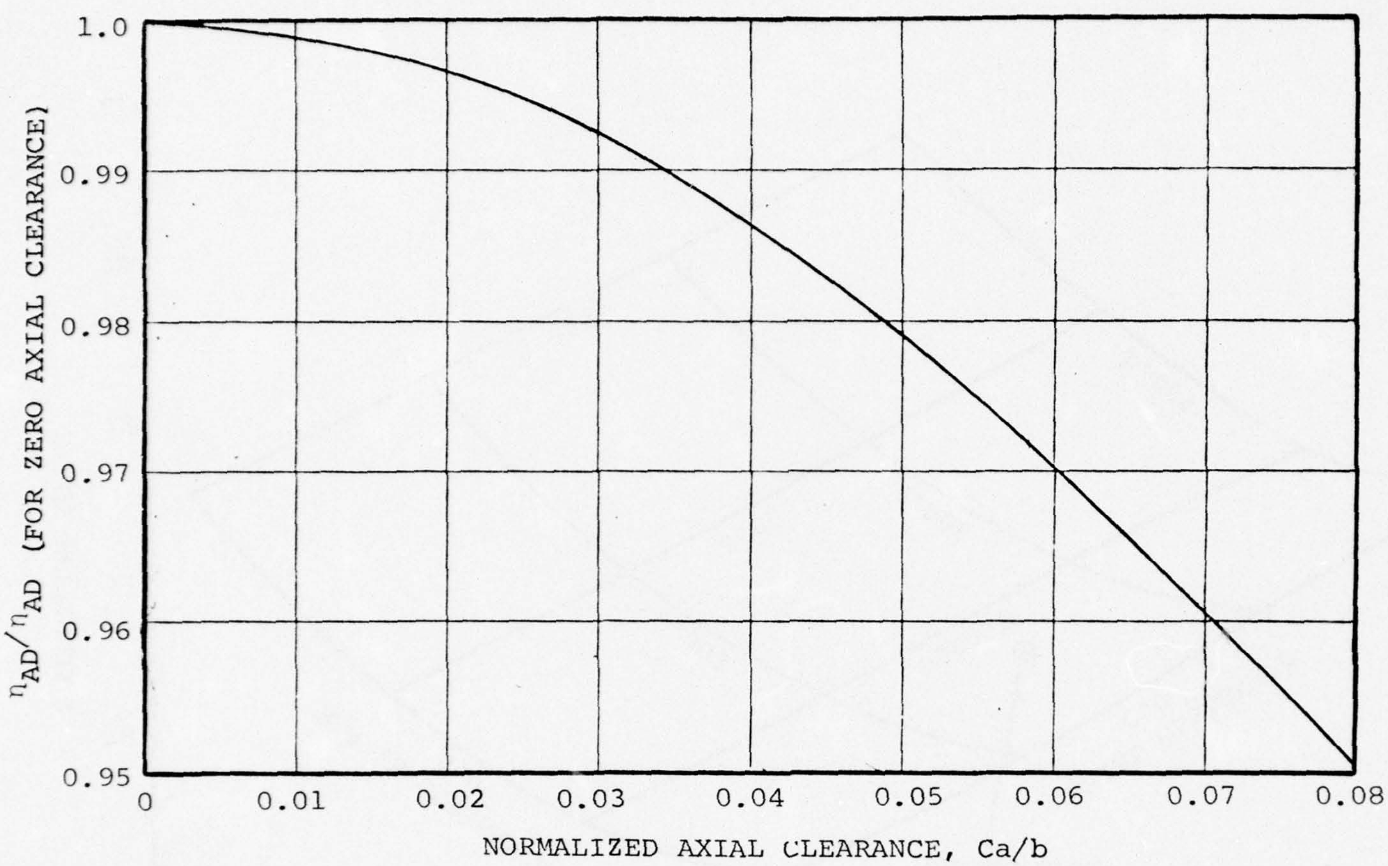
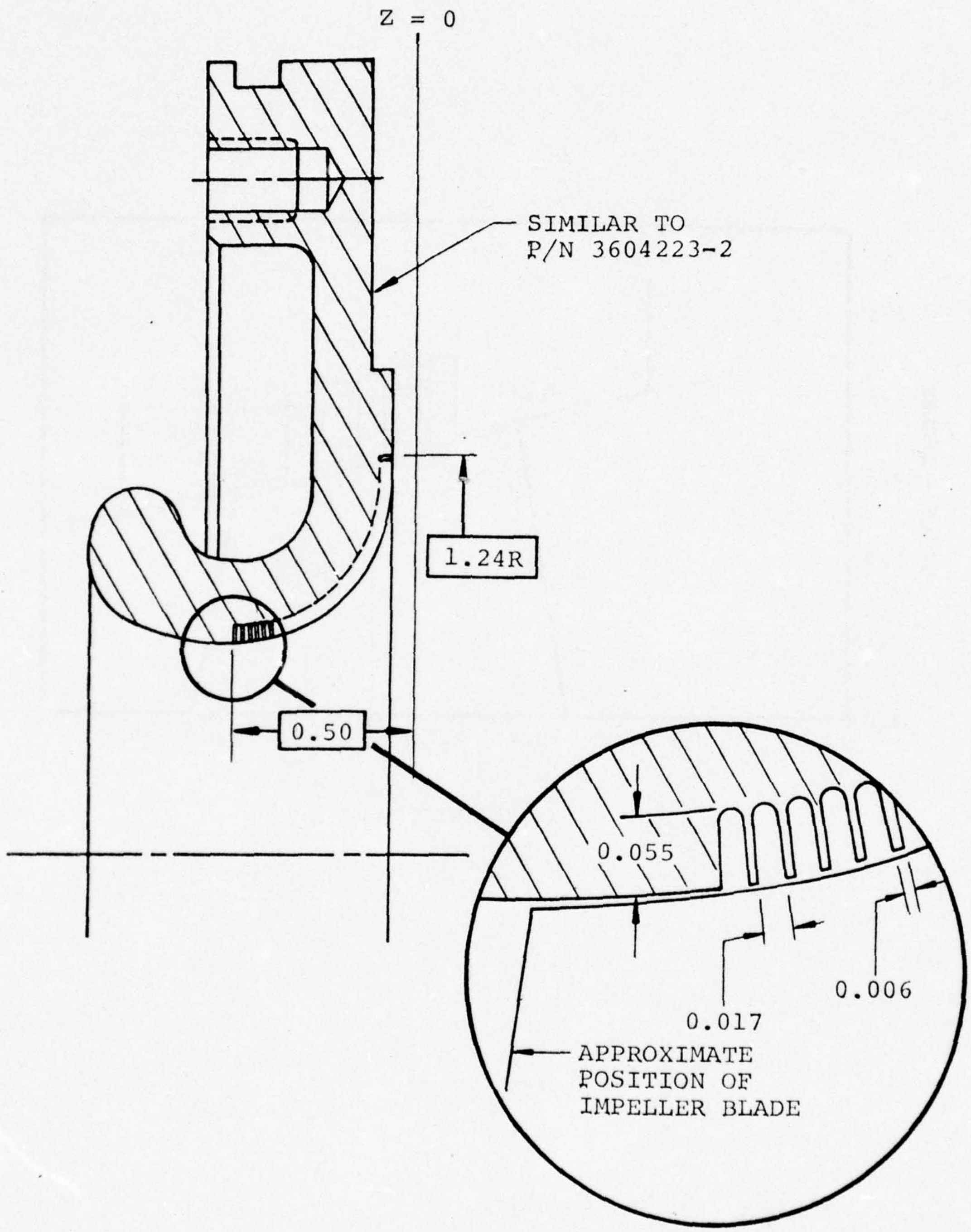


Figure 15. Relationship Between Compressor Efficiency and Normalized Axial Clearance.



DETAIL DESIGN OF CASING TREATMENT

Figure 16. Casing Treatment Detail Design.

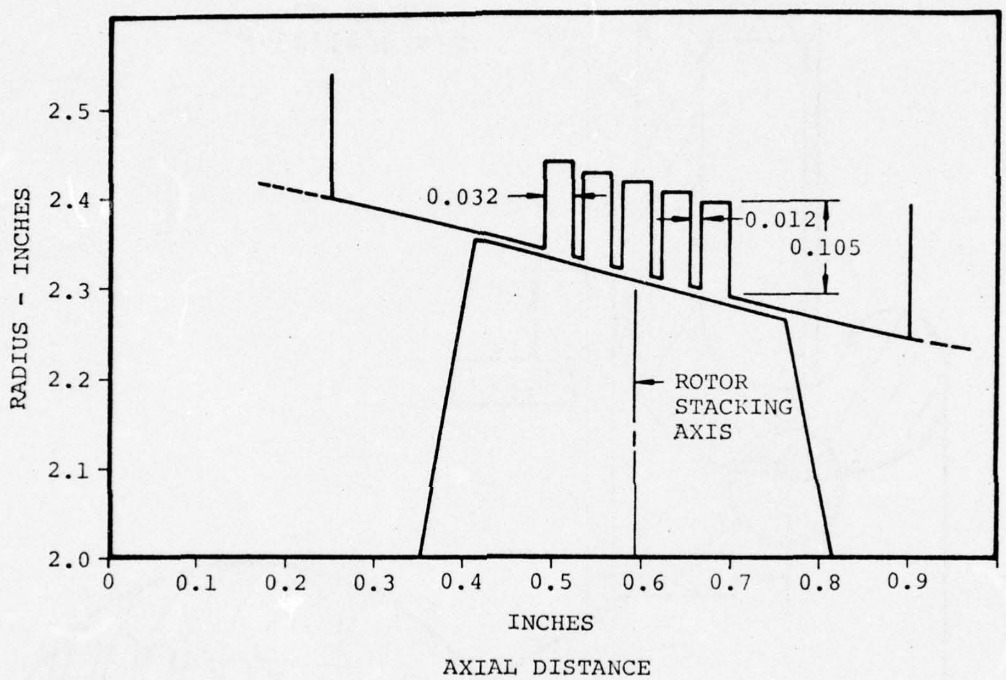


Figure 17. Grooved Casing Insert Design for a Small Axial Compressor.

2.3.4 Diffuser Design

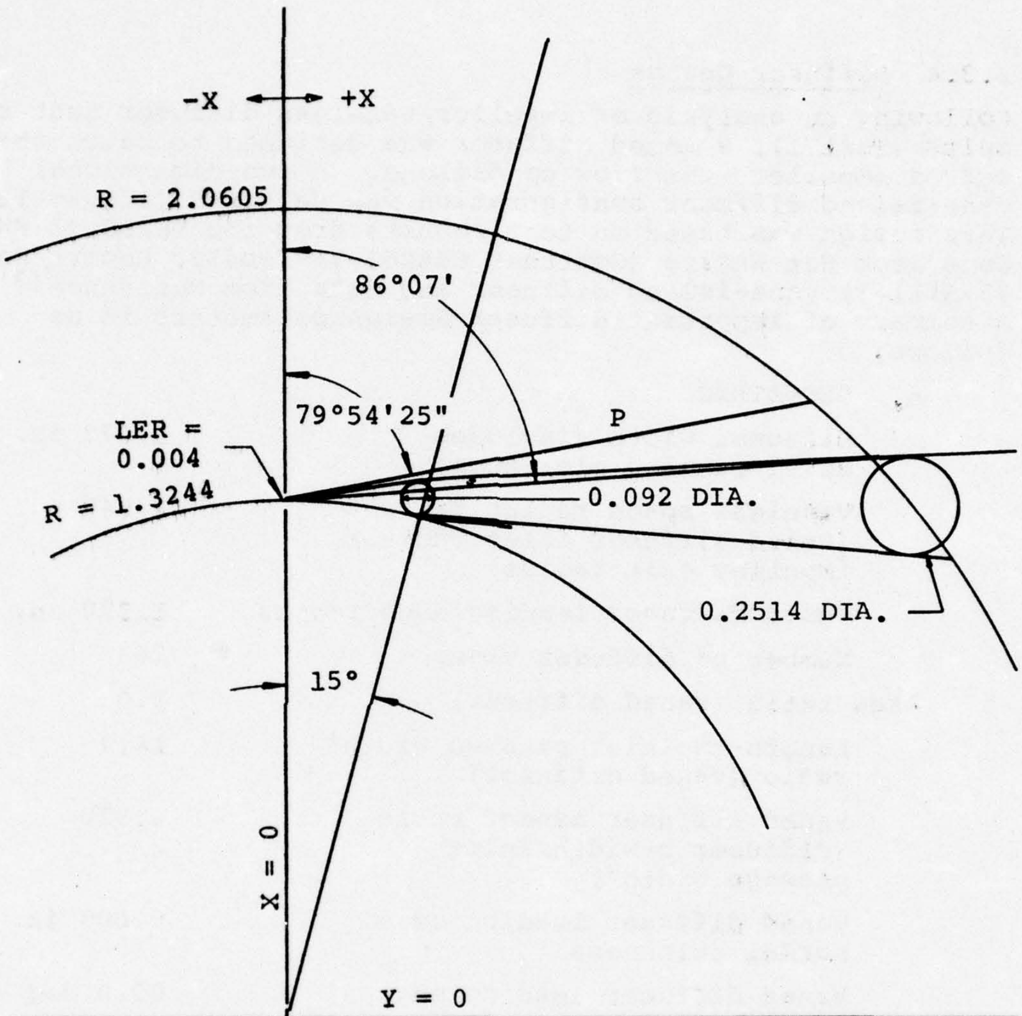
Following an analysis of impeller/vaneless diffuser test results (Test 1), a vaned diffuser was designed to match observed impeller exit flow conditions. A two-dimensional vane-island diffuser configuration was selected (Figure 18). This design was based on test results from the MERDC 30 KW Generator Set Engine (Contract DAAK02-74-C-0413, Report No. 75-311163) vane-island diffuser and data from Reference[3]. A summary of important diffuser design parameters is as follows:

A. GEOMETRIC

Diffuser width (includes axial running clearance)	0.077 in.
Vaneless space radius ratio (vaned diffuser inlet radius/ impeller exit radius)	1.046
Vaned diffuser leading edge radius	1.320 in.
Number of diffuser vanes	24
Area ratio (vaned diffuser)	3.0
Length-to-inlet passage width* ratio (vaned diffuser)	16.7
Vaned diffuser aspect ratio (diffuser b-width/inlet passage width*)	0.920
Vaned diffuser leading edge normal thickness	0.008 in.
Vaned diffuser leading edge meanline angle	80.0 deg
Vaned diffuser throat to inlet passage width* ratio	1.099
Vaned diffuser exit radius	2.060 in.
Vaned diffuser trailing edge normal thickness	0.150 in.

$$\text{*Inlet passage width} = \left(\frac{2\pi R\cos\beta_{flow}}{Z}\right)_{\text{Impeller exit}}$$

(3) <u>Pressure Recovery Performance of Straight-Channel Single-Phase Divergence Diffusers at High Mach Numbers</u>, USAAVLABS Report No. 69-56, P.W. Runstadler



Xs	Ys	X_P	Y_P
-0.0040	1.3244	-0.0040	1.3244
-0.0000	1.3204	-0.0000	1.3284
-0.0500	1.3286	-0.0500	1.3373
-0.1000	1.3370	-0.1000	1.3463
-0.1500	1.3450	-0.1500	1.3552
-0.2000	1.3534	-0.2000	1.3664
-0.2500	1.3614	-0.2500	1.3735
-0.3000	1.3695	-0.3000	1.3827
-0.3500	1.3758	-0.3500	1.3915
-0.4000	1.3790	-0.4000	1.4005
-0.4500	1.3813	-0.4500	1.4095
-0.5000	1.3830	-0.5000	1.4180
-0.6000	1.3872	-0.6000	1.4360
-0.7000	1.3915	-0.7000	1.4535
-0.8000	1.3955	-0.8000	1.4715
-0.9000	1.3995	-0.9000	1.4892
-1.0000	1.4040	-1.0000	1.5070
-1.1000	1.4080	-1.1000	1.5250
-1.2000	1.4120	-1.2000	1.5430
-1.3000	1.4160	-1.3000	1.5610
-1.4000	1.4205	-1.3380	1.5675
-1.4895	1.4240		

Figure 18. 1.5/3 kW Test Rig Diffuser Vane
(Drawing No. TL3621486).

B. AERODYNAMIC

Compressor inlet corrected flow	0.138 lb/sec
Impeller exit effective area	0.8825 in.^{2}
Impeller exit mach number	0.892
Impeller pressure ratio (total-to-total)	3.692
Impeller exit total pressure*	52.142 lb/in.^{2}
Impeller exit total temperature*	809°R
Impeller efficiency (total-to-total)	0.821
Impeller exit absolute flow angle (β_{flow})	75.3 deg.
Vaned diffuser inlet effective area	0.9526 in.^{2}
Vaned diffuser incidence angle (impeller exit swirl angle minus the vaned diffuser leading edge meanline angle)	-4.7 deg
Vaned diffuser inlet Mach number (based on a 0.9526 effective area at the vaned diffuser inlet)	0.812
Vaned diffuser exit average Mach number (prior to dumping)	0.191
Static pressure rise coefficient (C_p) (impeller exit to vaned diffuser exit prior to dumping)	0.728
$\bar{\omega}$, Diffuser loss coefficient (impeller exit to vaned diffuser exit prior to dumping)	0.215

*Standard Day Condition

Compressor efficiency (total-to-total)	0.754
Compressor pressure ratio (total-to-total)	3.372
Compressor total temperature rise ($\Delta T/T$)	0.547

The fabrication method selected for the diffuser was to machine the vanes from a plate to achieve a vane fillet radius of 0.005 in. or less. Slots were Eloxed in a second plate that fit over the vanes. An additional plate, designed to be brazed to the second plate, eliminated any fillet radius between the second plate and vanes, while anchoring the second plate to the vanes. This manufacturing method was chosen due to the small diffuser size that necessitated extremely tight tolerances and a minimization of fillet size. The material used was 17-4PH steel. A photograph of the diffuser, showing only the plate with the machined vanes, is shown in Figure 19. Figure 20 shows the finished piece.

The diffuser drawing number is 3604748 (Figure 21) and the vaned diffuser tooling layout drawing number is TL3621486 (Figure 18).

2.3.4.1 Vaned Diffuser Inlet Conditions

Due to the low specific speed and small size of the impeller, an accurate value of effective area (geometric area minus boundary layer blockage) at the impeller exit is difficult to deduce. Test 1, Data Scan 45 was used to define diffuser design point conditions (the corrected flow is 0.139 lb/sec versus 0.138 lb/sec impeller design point). This scan was examined in the data reduction computer program for assumed impeller exit effective areas of 80, 85, and 90 percent.

Figure 22 shows that the impeller exit absolute air angle is a function of impeller exit effective area. Selection of the proper value of this air angle determines the vane leading edge meanline angle and the loss is defined as follows:

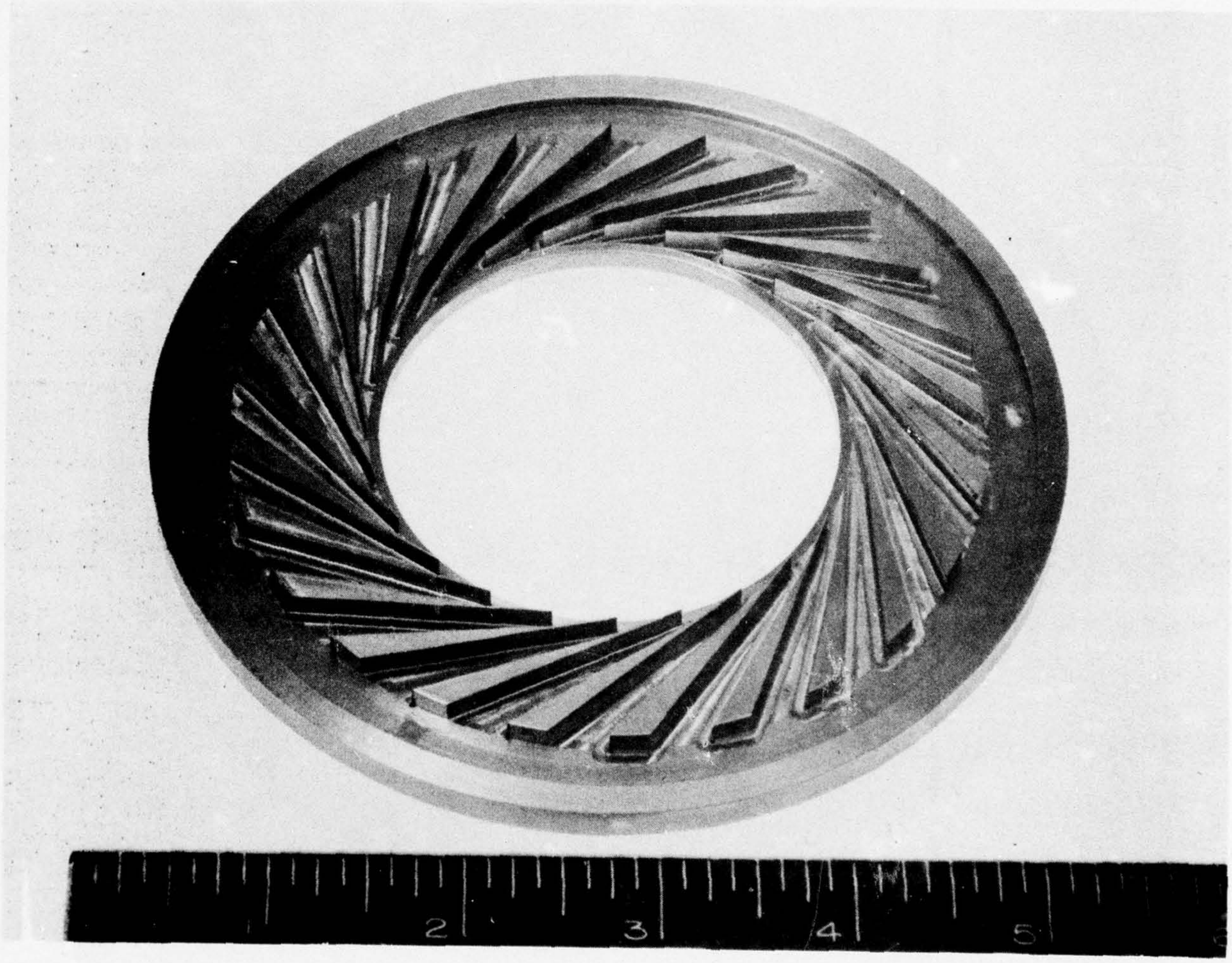


Figure 19. Photograph of 1.5/3 KW Diffuser Showing Machined Vanes.

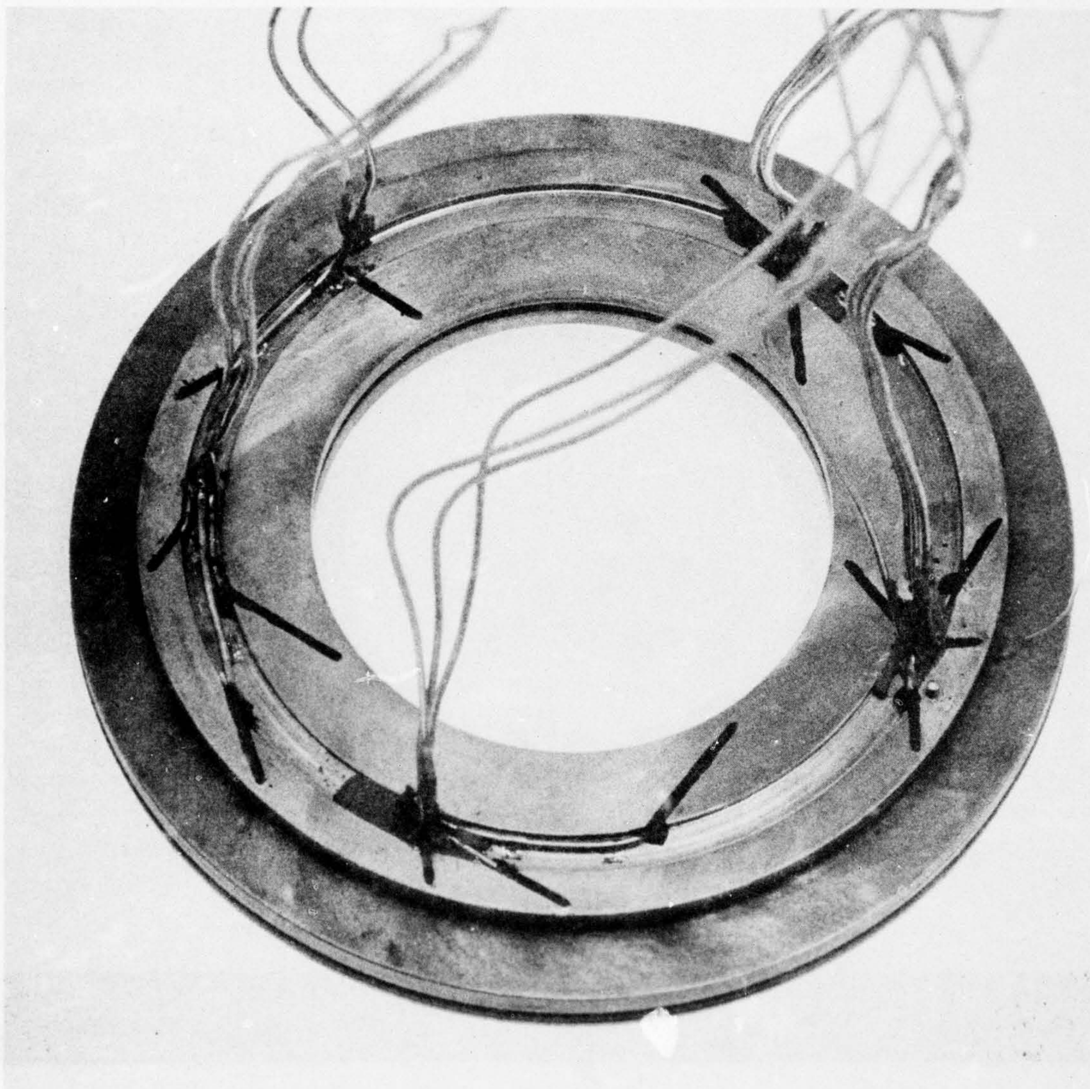


Figure 20. Photograph of Instrumented Diffuser.

MP-52435

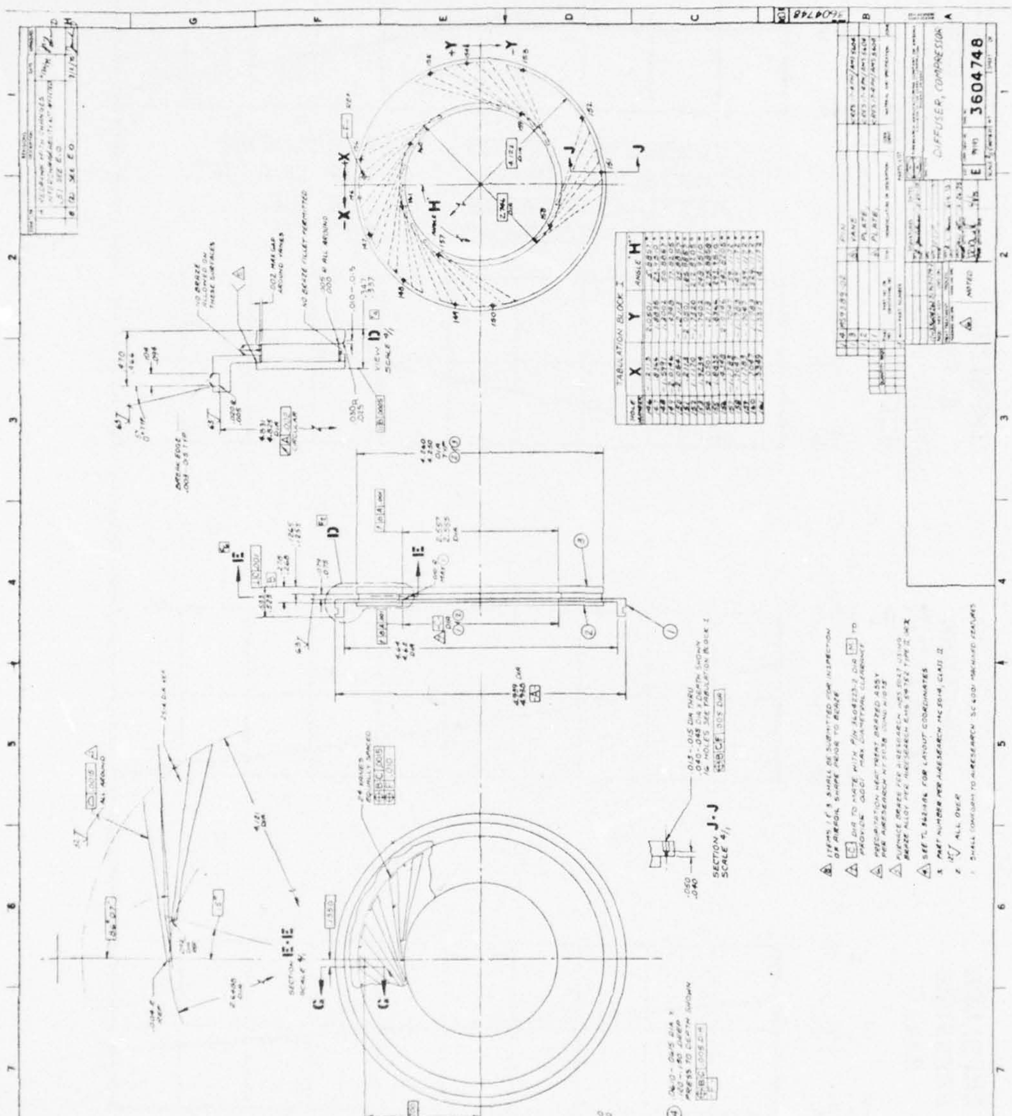


Figure 21. Diffuser (Drawing No. 3604748).

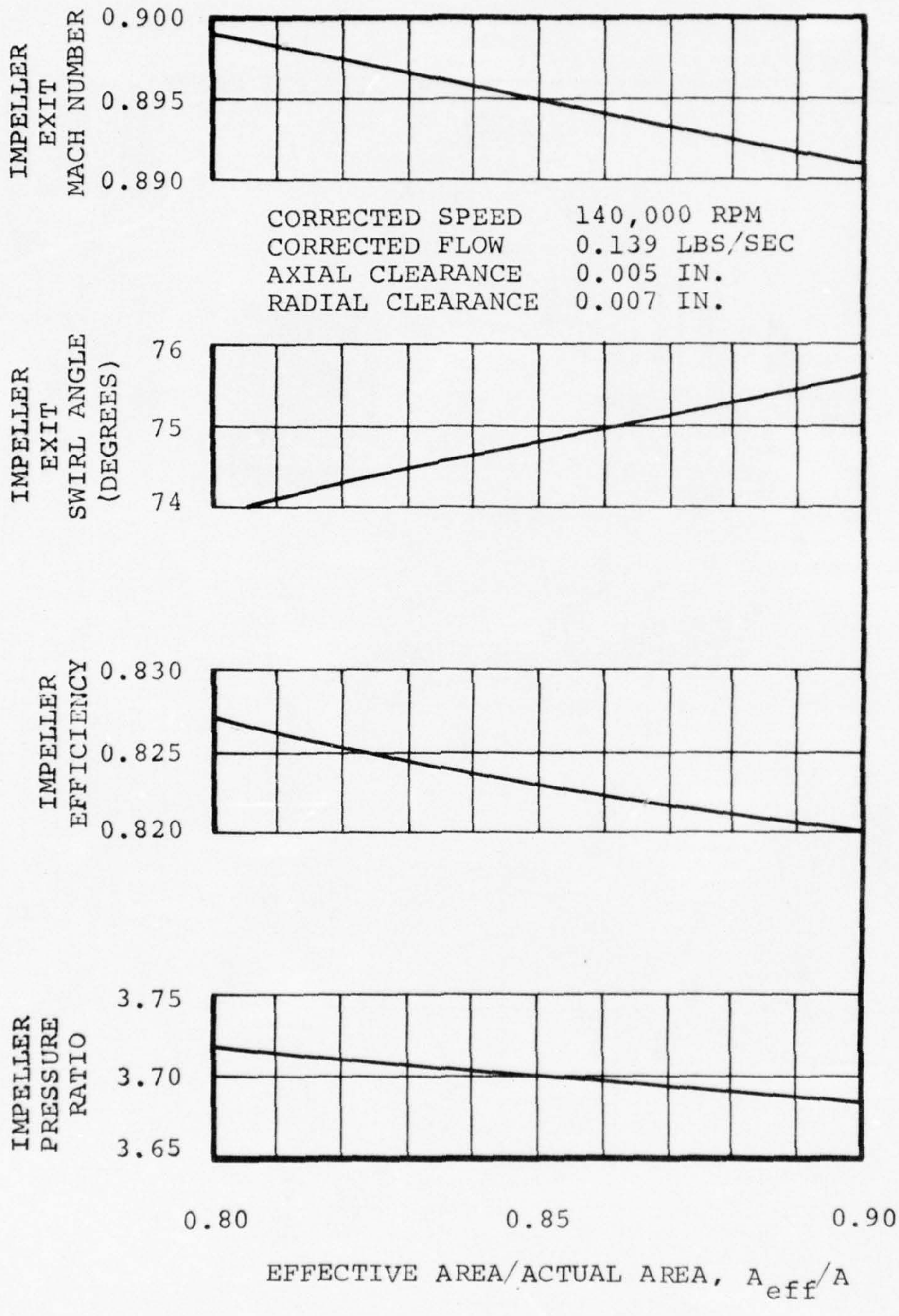


Figure 22. 1.5/3 kW Effective Area Study Using Scan 45 of Test 1.

$$\bar{\omega} = \frac{P_{o_{2.5}} - P_{o_{3.0}}}{P_{o_{2.5}} - P_{s_{2.5}}}$$

where

$\bar{\omega}$ = diffuser loss coefficient

$P_{s_{2.5}}$ = impeller exit static pressure

$P_{o_{2.5}}$ = impeller exit total pressure

$P_{o_{3.0}}$ = vaned diffuser exit total pressure (prior to dumping)

To correctly match the diffuser minimum loss point with the compressor impeller design point, it was necessary to analytically establish the impeller exit blockage value. To do this, a Reynolds number correlation was used based on scaling a larger, typical impeller to the 1.5/3 kW size. The equation used for this is as follows:

$$\frac{(1 - A_{effective})_{3\ kW}}{(1 - A_{effective})_{typ}} = \left(\frac{\text{Re. No.}_{typ}}{\text{Re. No.}_{3\ kW}}\right)^{0.17}$$

Where $A_{effective}$ is the effective area at the impeller exit and the Reynolds number is defined as:

$$\text{Re. No.} = \frac{\rho_{0_1}\ U_T\ D_T}{\mu}$$

where

ρ_{o_1} = impeller inlet stagnation density (slugs/ft^3)

U_T = impeller tip speed (ft/sec)

D_T = impeller tip diameter (ft)

μ = impeller inlet viscosity (slugs/ft-sec)

Inserting the proper values into the equation produced an impeller exit effective area of 0.8825 versus the usual value of 0.90 that has yielded a good match between analytical work and test results for larger impellers.

Interpolating from Figure 22 for the 0.8825 effective area, yielded the following impeller exit conditions:

Impeller exit total pressure	= 52.142 $lb/in.^2$
Impeller exit Mach number	= 0.892
Impeller exit absolute flow angle	= 75.44 degrees
Impeller efficiency (total-to-total)	= 0.821

2.3.4.2 Selection of Vaneless Space Radius Ratio, Aspect Ratio, Incidence, and Throat/Inlet Passage Width Ratio

The vaneless and semi-vaneless diffuser regions (that region of vaned diffuser from leading edge to throat) were designed based on MERDC 30 KW Generator Set Engine diffuser data (reference diffuser) that had minimum loss coefficients ($\bar{\omega}$ in the range of impeller exit Mach numbers of interest for the 3 kW compressor (see Figure 23). A slight modification was made in the geometric throat-to-inlet passage width ratio of the diffuser due to physical constraints.

The vaneless space radius ratio was selected to be identical to that used for the reference diffuser to allow use of the reference diffuser incidence angle. A diffuser throat-to-inlet passage width ratio of 1.099 was used. This ratio is slightly smaller than the reference diffuser (1.115 diffuser throat to inlet passage width ratio). The difference was required to retain a reasonable vane thickness at the diffuser throat.

Twenty-four vanes were chosen for the diffuser to keep the aspect ratio (defined as b-width/inlet passage width) at a value of 0.92 versus a value of 0.918 for the reference diffuser. The basis of this choice is that, from Runstadler[3], an aspect ratio near one appears to yield near optimum diffuser performance.

2.3.4.3 Design of the Diffuser from the Throat to the Exit

The remainder of the diffuser, featuring straight wall pressure and suction surfaces, was designed to produce

(3) Pressure Recovery Performance of Straight-Channel, Single-Plane Divergence Diffusers at High Mach Numbers, USAAVLABS Report No. 69-56, P.W. Runstadler.

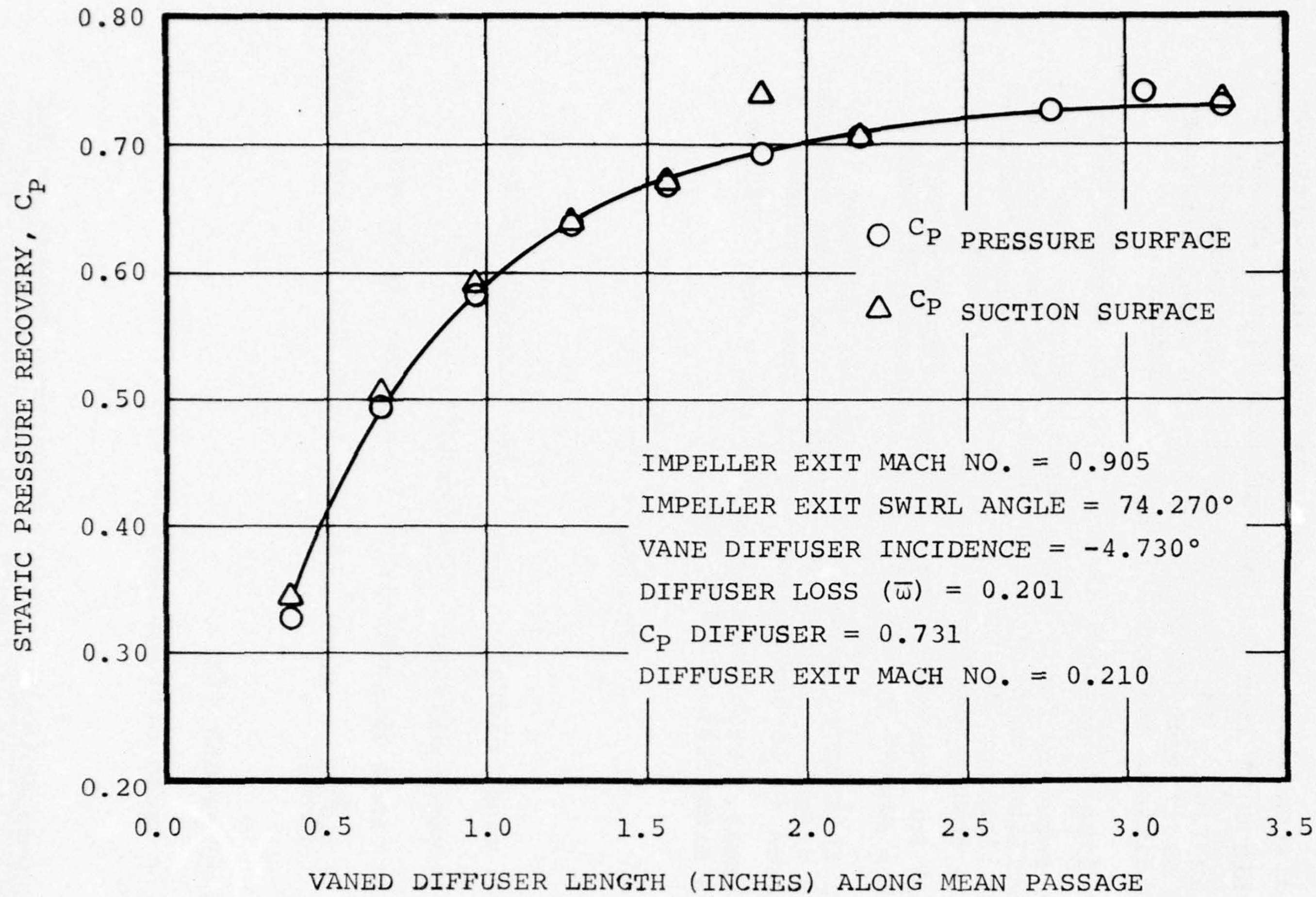


Figure 23. MERDC 30 kW Test 3 (Scan 34) Diffuser Performance.

an area distribution along the C_p** line [see Reference (4)]. This C_p** line was derived from Figure 25 and is plotted in Figure 24. Figure 25, from Runstadler[(3)], was used as it most closely matches the vaned diffuser inlet conditions (except for Reynolds number).

The C_p** line is defined as yielding the maximum static pressure recovery for a given vaned diffuser area ratio. It was utilized on this design due to the large radius ratio available. The fact that it is a "slower" diffusion than that found along the C_p* line [see Reference (4)] used for the reference diffuser, should result in less total pressure loss than the reference diffuser.

However, this anticipated lower value of diffuser loss could be offset by the small diffuser size (the diffuser throat area is 15 percent of the reference diffuser throat area). From Runstadler[(3)], the vaned diffuser Reynolds number if defined as:

$$\text{Re. No.} = \frac{\rho V D_h}{\mu}$$

where

V = vaned diffuser inlet core velocity (ft/sec)

ρ = vaned diffuser inlet density (lb/ft^3)

μ = vaned diffuser inlet viscosity (lb/ft-sec)

$D_h = \frac{2b}{(1-AS)}$ = vaned diffuser hydraulic diameter (ft)

and

b = b-width (ft)

AS = vaned diffuser aspect ratio

(4) Experimentally Determined Optimum Geometrics for Rectilinear Diffusers with Rectangular, Conical, or, Annular Cross-Section; General Motors Research Laboratories Publication No. GMR-511, E.D. Klomp and G. Sovran.

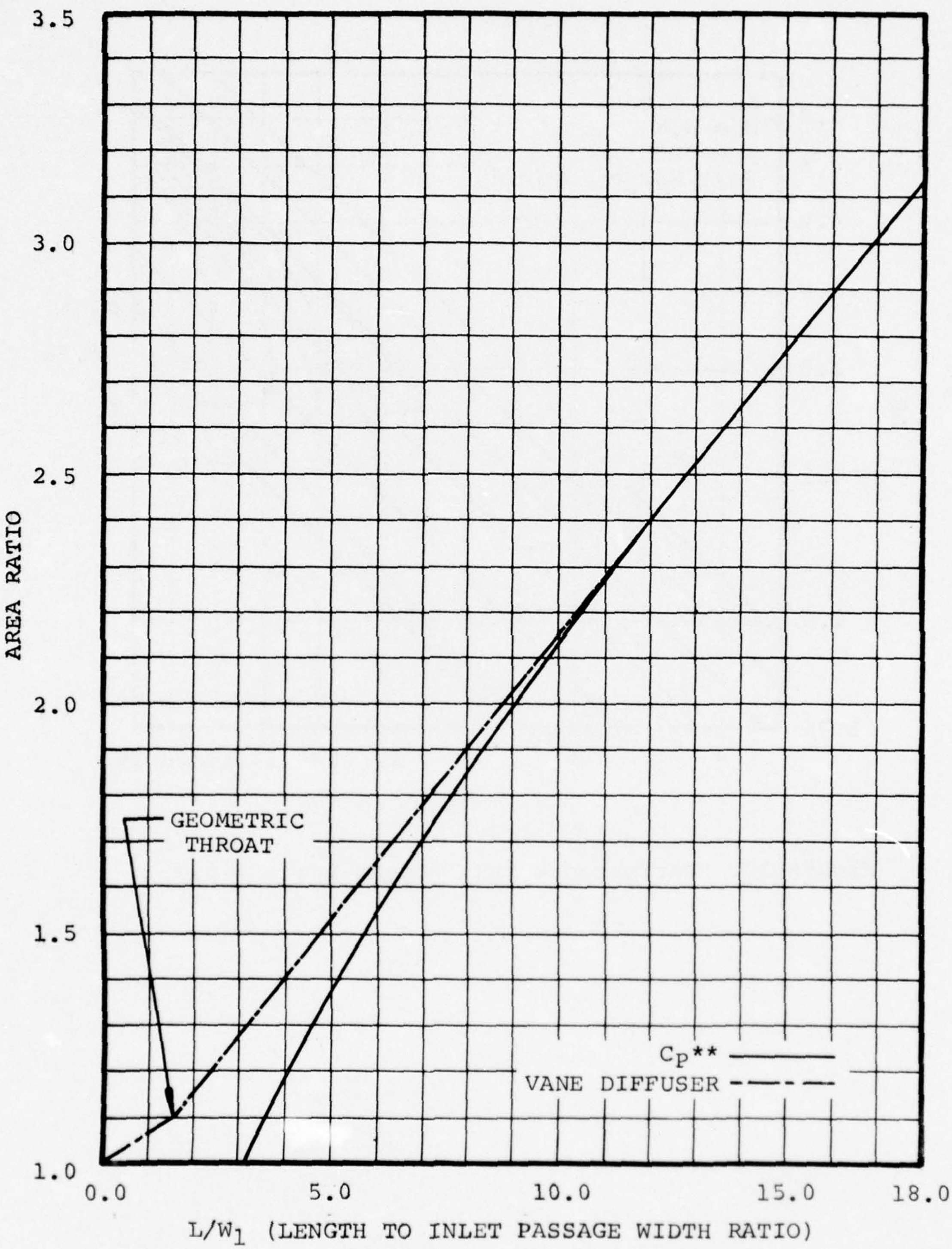


Figure 24. 1.5/3 kW Diffuser C_p** Line From Runstadler Data.

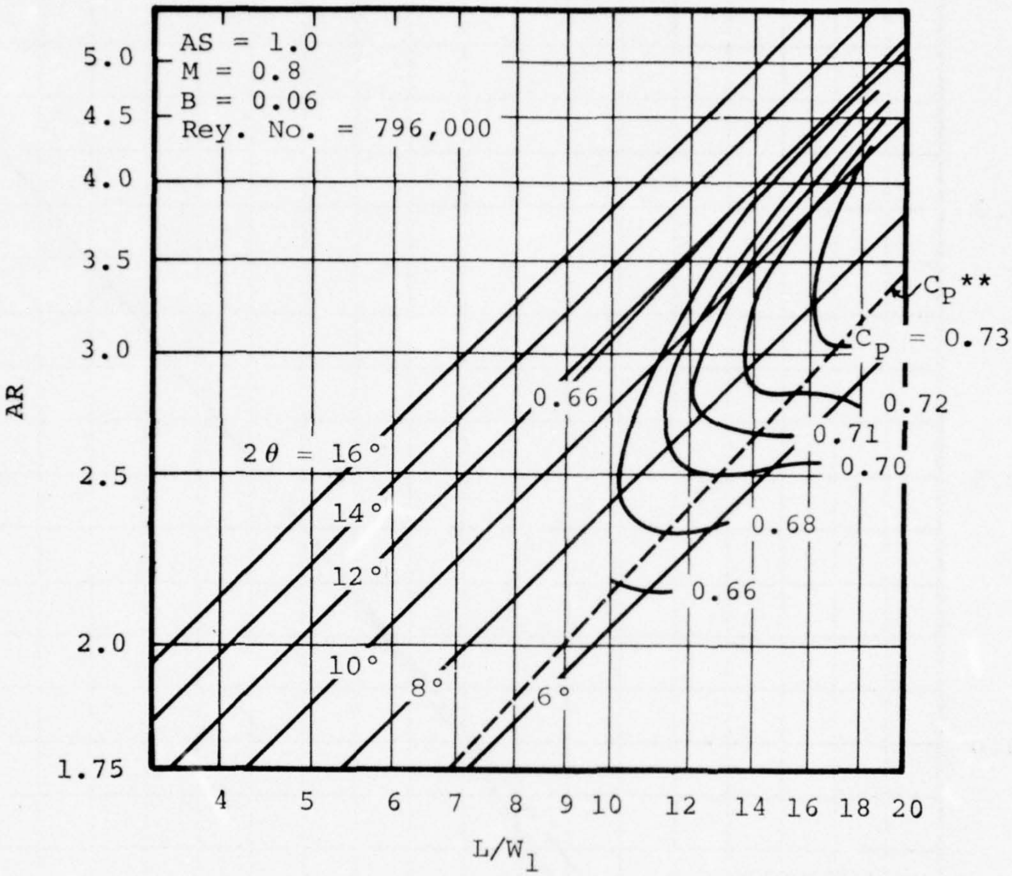


Figure 25. Performance Map, Aspect Ratio = 1.0.

This Reynolds number was calculated at the vaned diffuser inlet that corresponds to the location where the Reynolds number was calculated by Runstadler. A Mach number of 0.812 (based on a 0.9526 vaned diffuser inlet effective area) yields a Reynolds number of 5.93×10^4 for the diffuser. This is approximately one thirteenth of that used to generate the diffuser performance of Figure 23. This lower Reynolds number results in degraded vaned diffuser performance, but the effect of the Reynolds number on vaned diffuser performance becomes less as the Mach number approaches one. Since the Mach number is 0.812, there should be only slight degradation in the diffuser predicted performance due to the Reynolds number

The overall vaned diffuser area ratio was established based on the desire to diffuse to a typical engine value of Mach number before entry into the combustor. An average Mach number of 0.2 at the vaned diffuser exit (prior to dumping) is consistent with that goal and was set as the design objective. From Figure 24, the necessary area ratio of 3.0 corresponds to an L/W_1 (length-to-inlet passage width ratio) of 16.7. This yields, from Figure 25, an estimated pressure recovery coefficient (C_p) of 0.728. In an attempt to evaluate the validity of this C_p value for the diffuser, the reference diffuser performance was examined.

To do this, the diffusion system was separated into two parts; (1) the impeller exit to the vaned diffuser throat and, (2) the vaned diffuser throat to the vaned diffuser exit (prior to dumping). Because the region from the impeller exit to the vaned diffuser throat is based on that of the reference diffuser, the same C_p value of 0.106 was estimated (see Figure 23). Here, C_p is defined as:

$$C_p = \frac{P_{s_{point}} - P_{s_{2.5}}}{P_{o_{2.5}} - P_{s_{2.5}}}$$

where

$P_{s_{2.5}}$ = impeller exit static pressure

$P_{o_{2.5}}$ = impeller exit stagnation pressure

$P_{s_{point}}$ = static pressure at any point in the diffusion system (prior to dumping at the vaned diffuser exit)

Then, using the vaned throat of the 1.5/3 kW diffuser as an area ratio of 1.0, an area ratio of 2.733 out to the vaned diffuser exit is necessary to achieve the 3.0 area ratio overall. Using the vaned throat of the reference diffuser as an area ratio of 1.0, this 2.733 area ratio produces an additional C_p of 0.622, which when coupled with the C_p of 0.106 from the impeller exit to the vaned diffuser throat, results in a C_p of 0.728 for the vaneless, semi-vaneless, and vaned diffusers. Because some diffusion is accomplished in the vaneless space, the C_p of 0.727 for the vaned diffuser alone, as predicted from Figure 25, appears optimistic.

It is possible that the 1.5/3 kW diffusion system will exhibit a C_p of less than the reference diffuser due to the Reynolds number of the reference diffuser being 2.4 times as large. However, as previously mentioned in this report, the more conservative loading of the 1.5/3 kW vaned diffusion could negate the effect of any Reynolds number difference. For aerodynamic performance predictions, a C_p value of 0.728 was used for the complete 1.5/3 kW diffusion system.

2.3.4.4 Two-Dimensional Turbulent Compressible Boundary Layer Analysis of the Vaned Diffuser

An analysis of diffuser performance was conducted by use of a Boundary Layer Computer Program. To establish the correct value of vaned diffuser inlet blockage, a Reynolds number correlation was used that is the same as that used to establish the impeller exit blockage but utilizing the Reynolds number definition used in Paragraph 2.3.4.3, herein.

A vaned diffuser inlet effective area of 0.96 was established for the reference diffuser. Due to the small size of the 1.5/3 kW diffuser, this was reduced to a value of 0.9526 by using the following relation:

$$\frac{(1 - A_{\text{effective}})_{3\ \text{kW}}}{(1 - A_{\text{effective}})_{\text{ref diffuser}}} = \left(\frac{\text{Re. No.}_{\text{ref diffuser}}}{\text{Re. No.}_{3\ \text{kW}}} \right)^{0.17}$$

where

$$(A_{\text{effective}})_{\text{ref diffuser}} = 0.96$$

A boundary layer analysis was run for the 0.9526 effective area. Results of this analysis are included in Appendix I for reference. Two parameters, the shape factor (H) and the static pressure recovery coefficient (C_p), deserve mention.

The shape factor has a maximum value of 2.1586 which is well below the separation value of 3.0 suggested by Reference (5). The C_p value of 0.7457 is slightly above that predicted by Figure 25 and the value expected for the 1.5/3 kW vaned diffuser based on data from the reference diffuser. This discrepancy is partially due to the vaned diffuser inlet effective area of Figure 25 being smaller than that used in the Boundary Layer Computer Program and, to the Boundary Layer Computer Program being a two-dimensional analysis that prevents it from modeling the three-dimensional flow found in the actual vaned diffuser.

2.4 Compressor Test Rig Design

This task resulted in the test rig design shown in Figure 26 (Drawing L3621229). The layout lower half shows the vaneless diffuser design while the upper half shows the vaned diffuser design.

The test rig was derived from a commercially available, small turbocharger. This unit was capable of operating with the anticipated thrust and could accommodate the impeller size without structural modifications.

(5) Calculation of the Flow in Axisymmetrical Diffusers With the Aid of the Boundary Layer Theory, AiResearch Report No. AD-5088-MR, H. Schlichting and K. Gersten, Braunschweig.

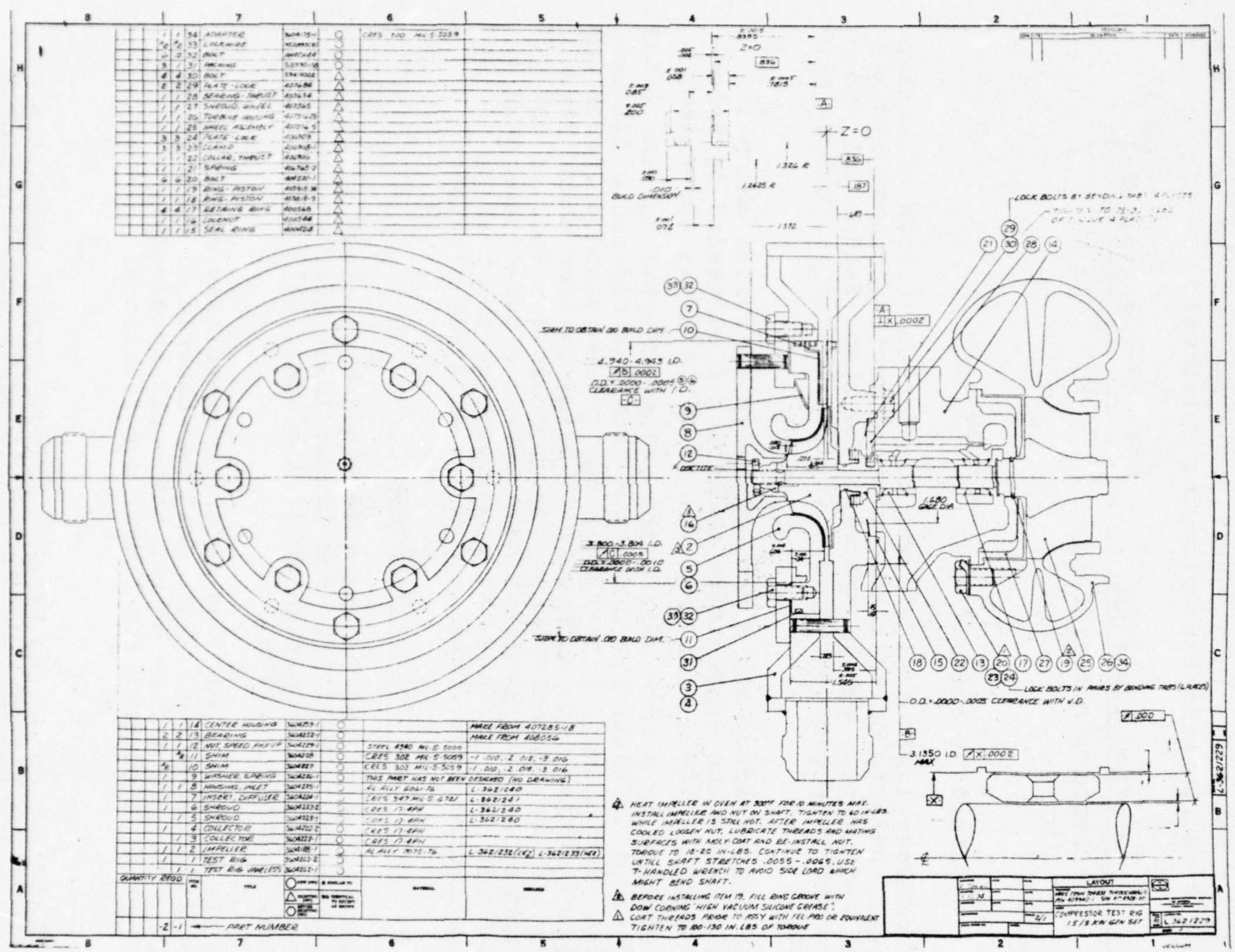


Figure 26. 1.5/3 kW Generator Set Compressor Test Rig (Drawing No. L3621229).

A radial inlet, opposed to a more efficient axial inlet, was selected for this rig because it is representative of the type inlet anticipated for an engine.

2.4.1 Compressor Rotor Stress Analysis

This task consisted of providing mechanical design of a test impeller suitable for demonstrating aerodynamic performance. The aluminum turbocharger impeller was replaced with an aluminum test impeller in the test rig. Aluminum was chosen for this impeller to retain the turbocharger rotating group dynamic characteristics, and for cost reasons.

Aluminum alloy, 7075-T651, was chosen for high strength and availability.

The compressor wheel stress model is shown in Figure 27. The somewhat unusual undercut at the forward end of the wheel provides clearance for static pressure measurement in the inlet. The cross-hatched portion of the wheel was added to the initial model to reduce both axial deflection (flowering) of the impeller tip and maximum stress.

The compressor wheel analysis was performed using an axisymmetric finite element computer program. Node locations and temperature distribution are shown in Figures 28 and 29, respectively. The burst ratio,

$$\left(\frac{0.85 \times \text{ultimate strength}}{\text{average tangential stress}}\right)^{1/2} = 1.96,$$ for this wheel shows a large safety margin.

Stresses (see Table XI and Figures 30 and 31) are caused primarily by centrifugal forces from wheel rotation and to a lesser extent by thermal gradient (Figure 29). The maximum stresses at 154,000 rpm, which is 10 percent above maximum operating speed (tangential = 36.9 ksi at node 234 and radial = 36.7 ksi at node 137), are below the minimum 0.2 percent yield strength = 62 ksi of 7075-T651 aluminum at 200°F. Maximum "flowering" (see Figure 32) was reduced to 0.0044 in. at Node 1.

Centrifugal blade stress was considered. Because of the high lean angle (29.2 degrees) at the blade inlet, bending stress adds to the mean tensile stress for a total stress in excess of 35 ksi (see Figure 33). Although this stress level is satisfactory for the 7075-T651 aluminum test rig impeller, it is considered excessive for production aluminum materials such as K01-T6 or 356-T6.

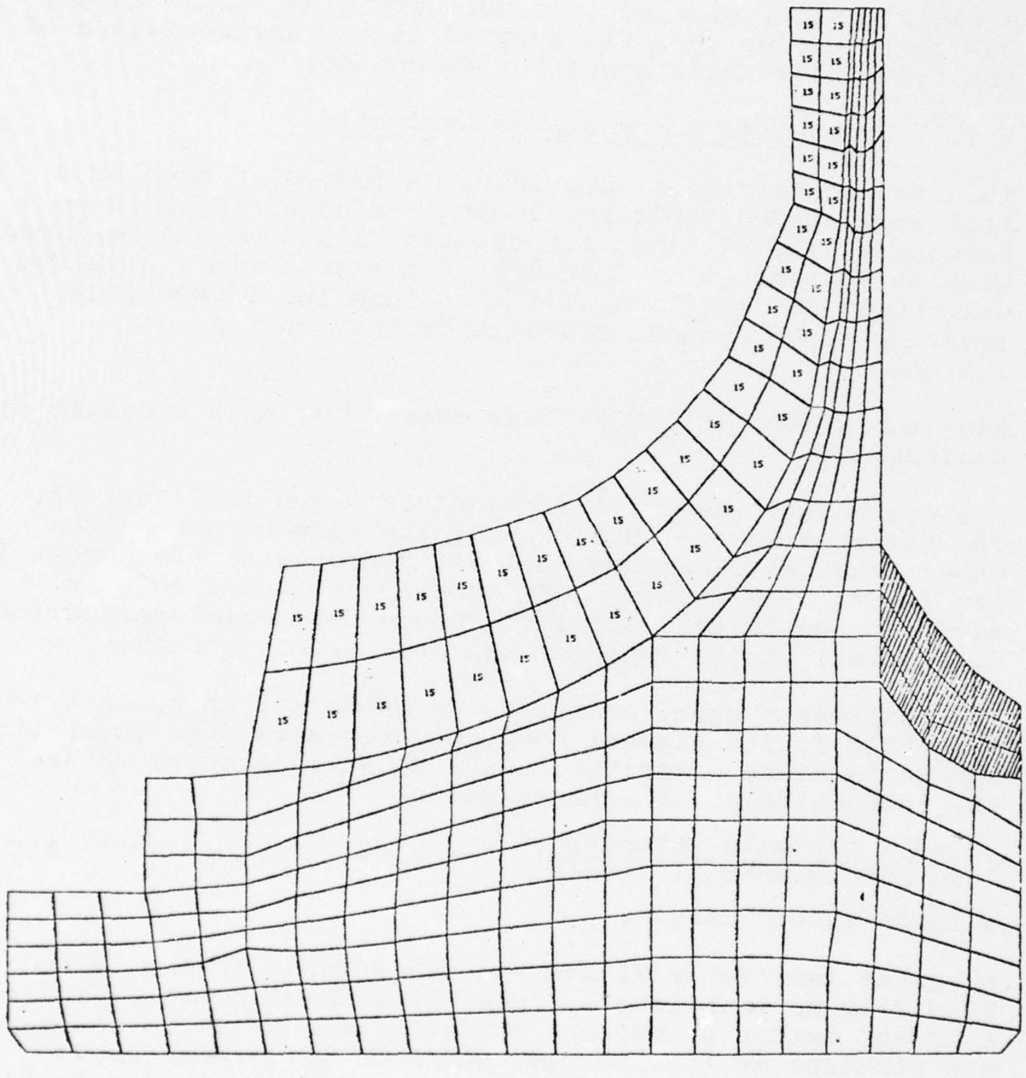
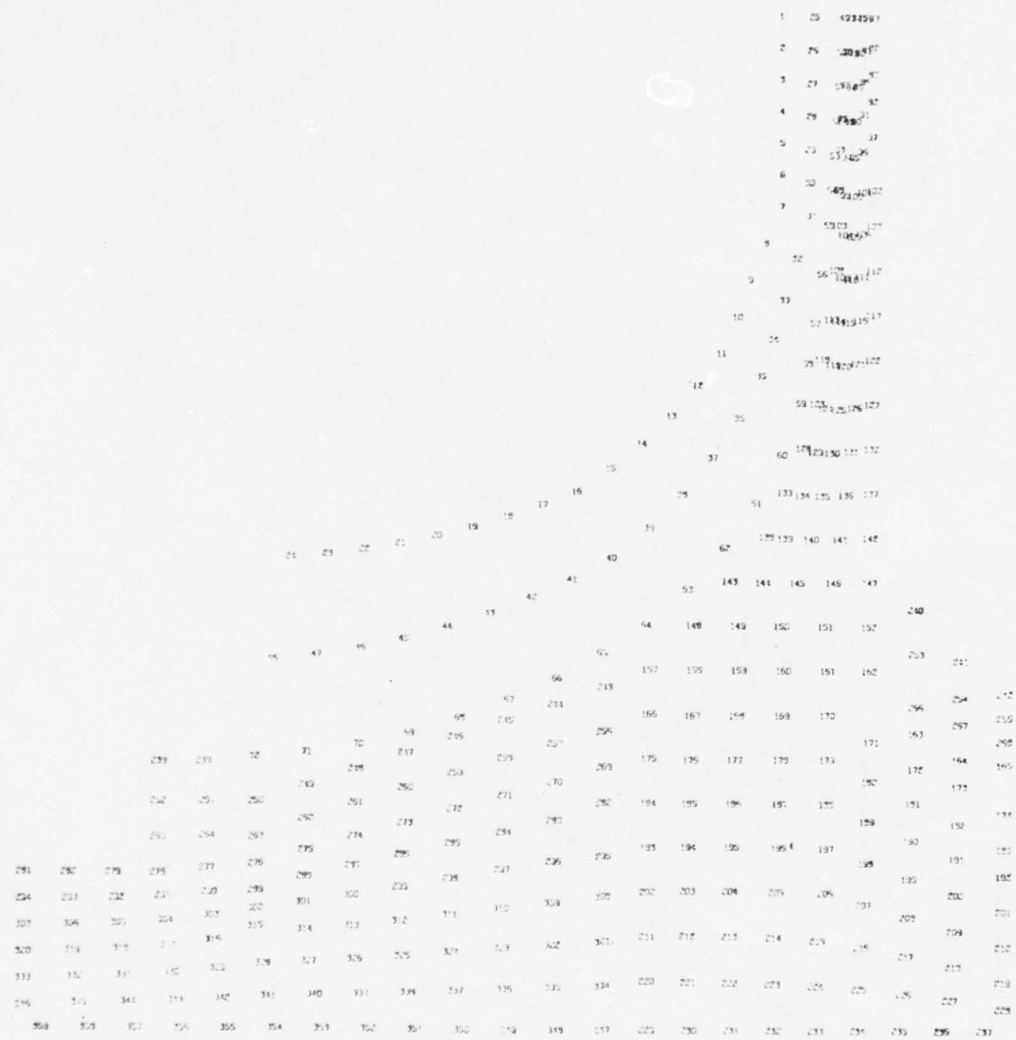
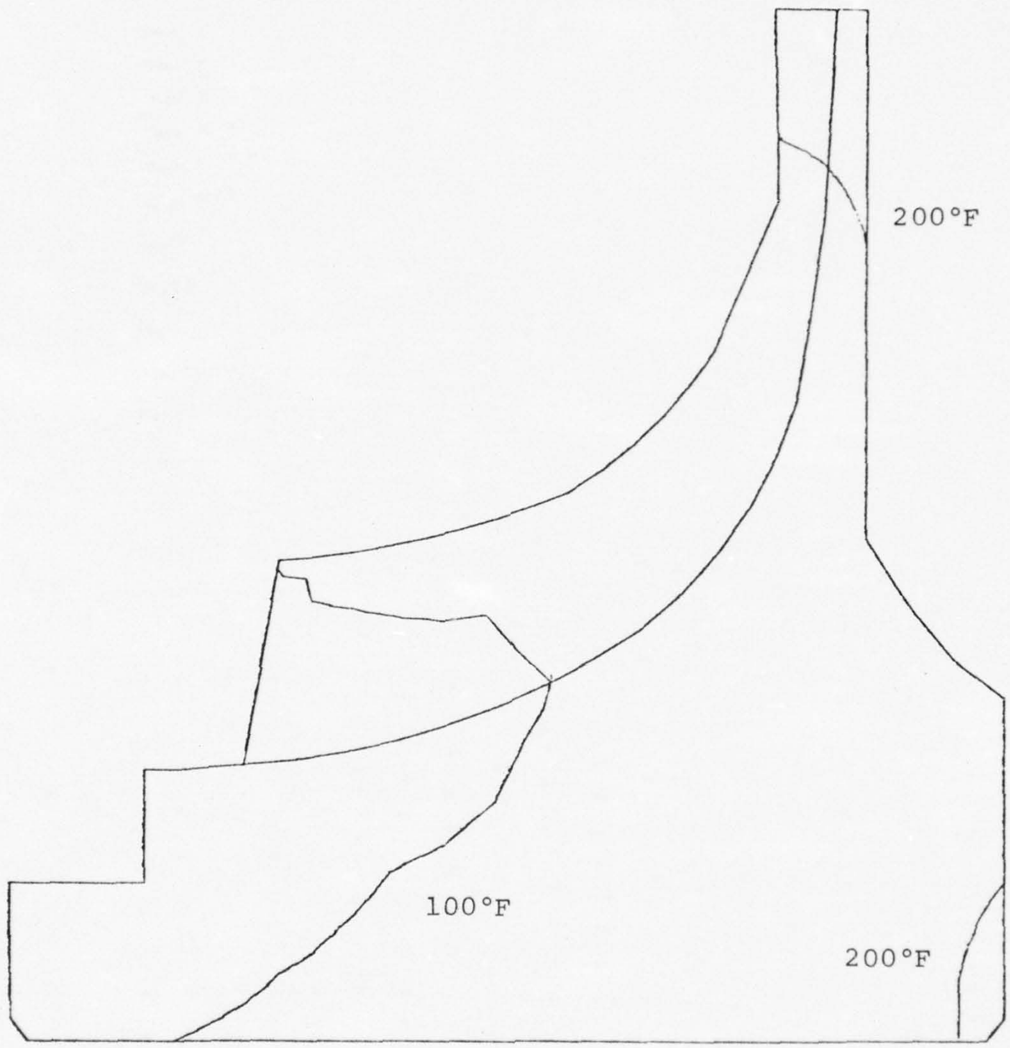


Figure 27. 1.5/3 kW Compressor Wheel Stress Model.



NODES

Figure 28. 1.5/3 kW Compressor Wheel Node Locations.



TEMPERATURES ARE FOR THE RATED POWER POINT AT SEA LEVEL, STANDARD DAY

Figure 29. 1.5/3 kW Compressor Wheel Temperature Distribution.

TABLE XI. RESULT SUMMARY, AXI-SYMMETRIC ELEMENTS

AMERICAN SYSTEM (KSI)

	Node	Stress
Maximum stress		
Principal	137	36.7
Equivalent	234	34.1
Radial	137	36.7
Tangential	234	36.9
Axial	240	7.6
Shear	137	17.4
Minimum stress		
Principal	228	-4.7
Axial	228	-4.4
Minimum S-R life, hours	-	-
Minimum M/S (ultimate)		
Principal	137	36.7
Equivalent	234	34.1
Radial	137	36.7
Tangential	234	36.9
Axial	240	7.6
Shear	137	17.4
Minimum M/S (yield)		
Principal	137	36.7
Equivalent	234	34.1
Radial	137	36.7
Tangential	234	36.9
Axial	240	7.6
Shear	137	17.4

Material: Aluminum 7075-T651
Rotational speed = 154,000 rpm

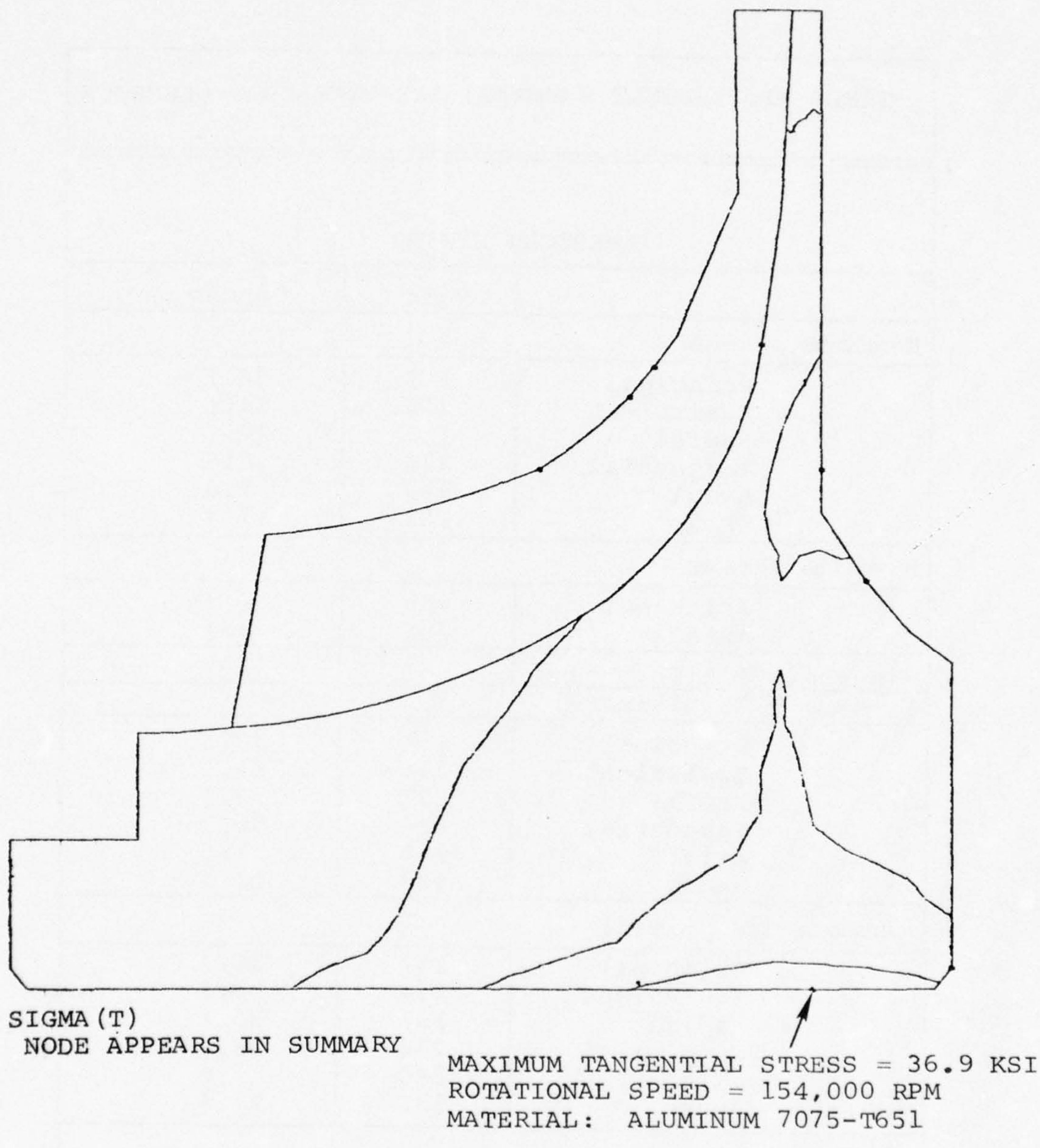


Figure 30. 1.5/3 kW Compressor Wheel Tangential Stress Locations.

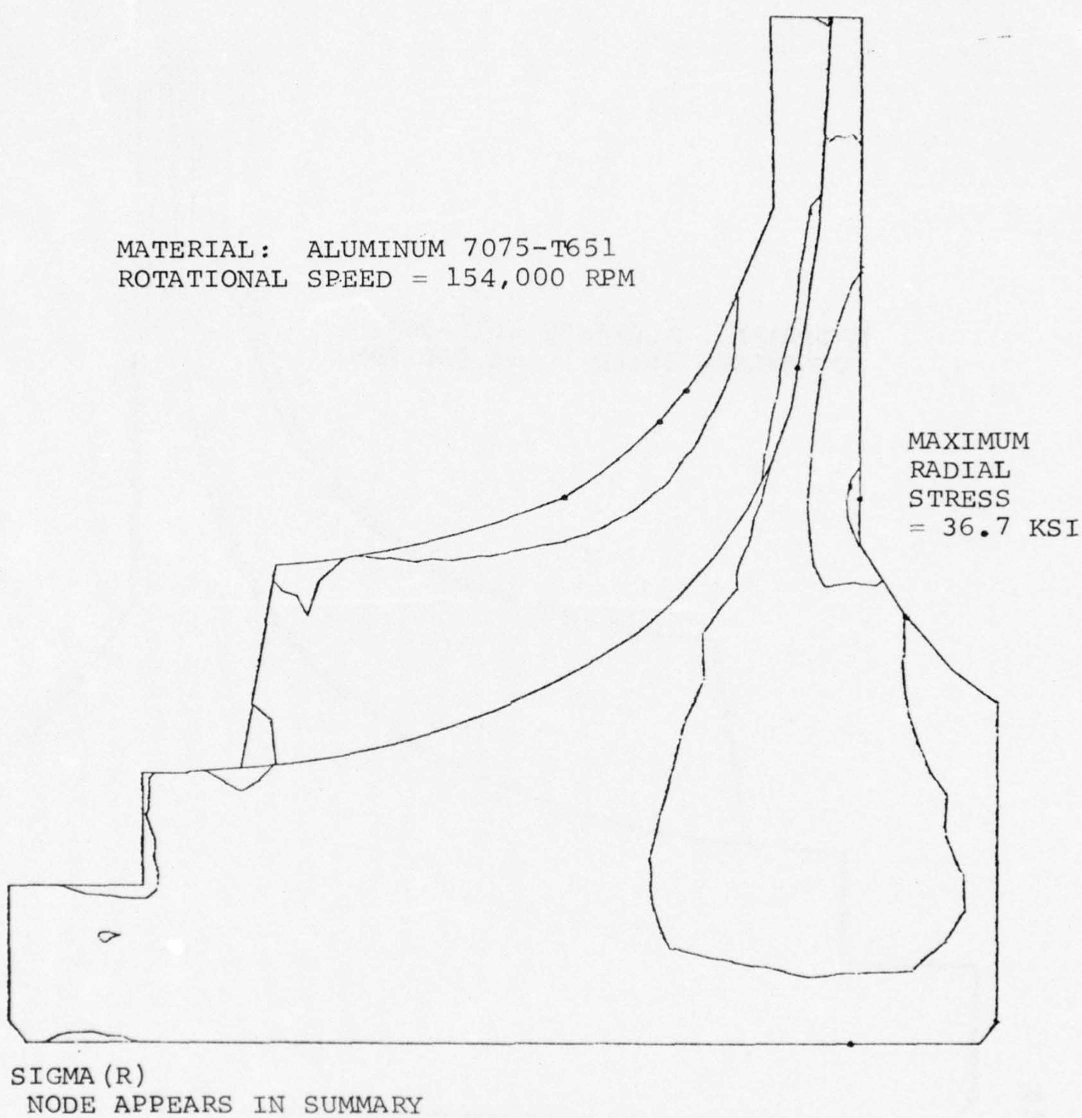


Figure 31. 1.5/3 kW Compressor Wheel Radial
Stress Locations.

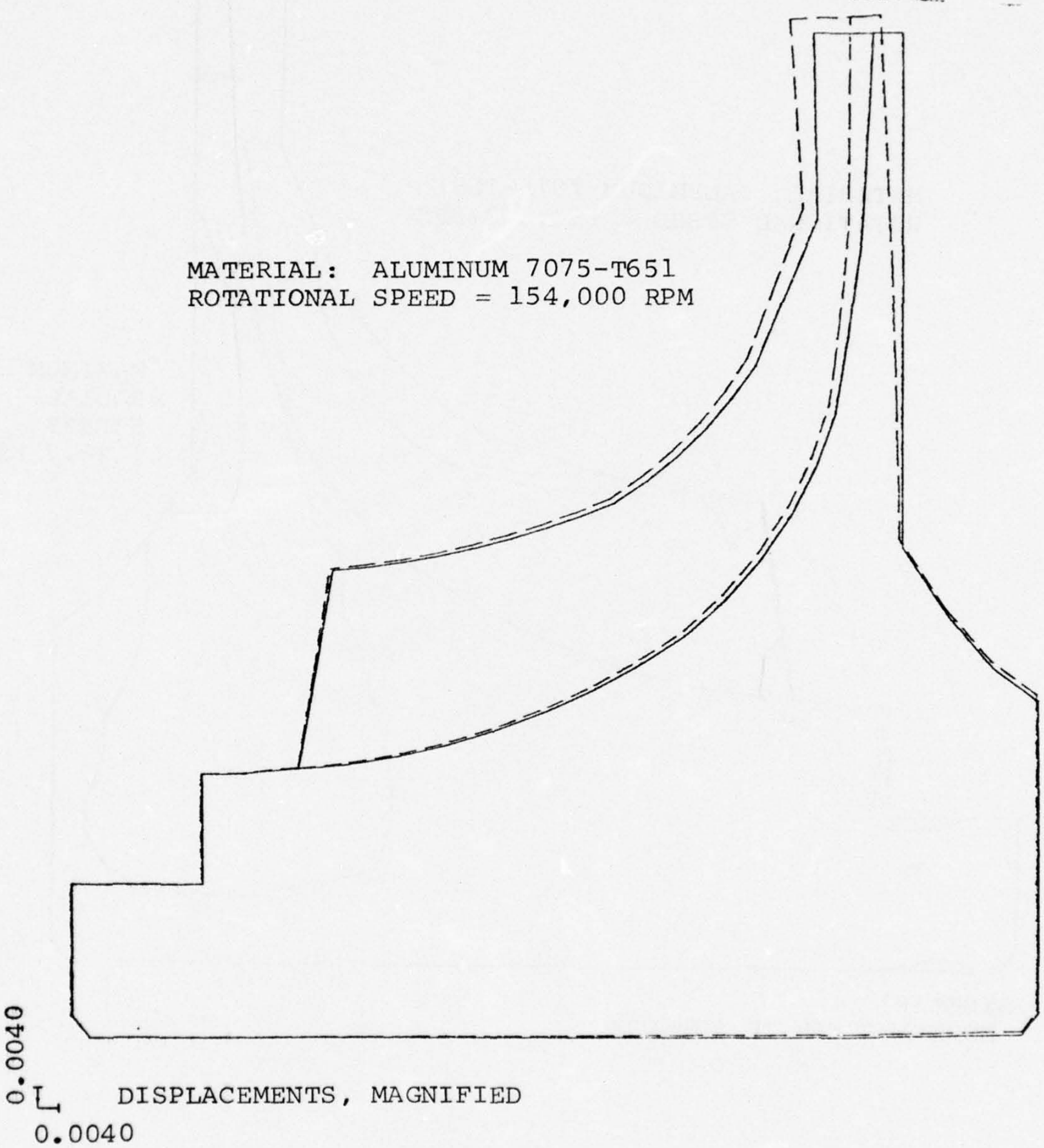


Figure 32. 1.5/3 kW Compressor Wheel Flowering.

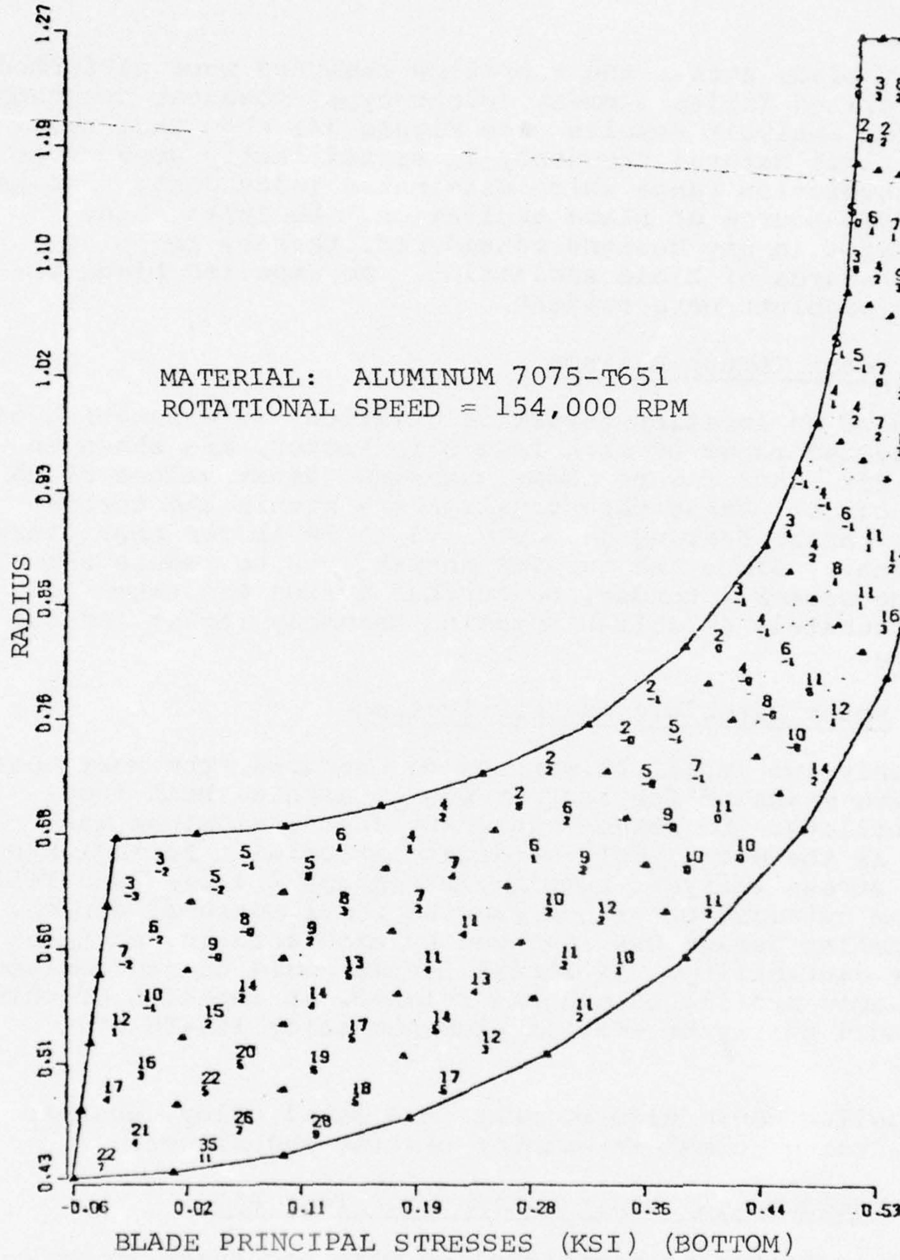


Figure 33. 1.5/3 kW Compressor Wheel Blade Principal Stresses.

Impeller blade stress and vibration analyses were performed using related finite element (plate-type) computer programs. Vibration analysis results (see Figure 34) show that the lowest blade natural frequency is significantly above 4 to 5 per revolution range which eliminates inlet distortion as a probable source of blade excitation. No inlet guide vanes exist in any designs considered, thereby removing another source of blade excitation. No impeller blade vibration problems were evident.

2.4.2 Rotor Thrust Balance

Results of an impeller thrust calculation, as a function of the expected range of back face Slip Factor, are shown in Figure 35. This figure shows expected thrust values of 38 to 48 pounds. These thrust values are within the turbocharger thrust bearing capacity (45 to 50 lb for short term operation). Since the turbine thrust acts to reduce net rotating assembly thrust, no further action was taken to more accurately establish rotating assembly thrust for the test rig.

2.4.3 Rotor Materials and Fabrication

Since only two impellers were to be procured, the most cost effective means of fabrication was to machine both from solid billets. To reduce machining costs, aluminum was chosen as the most likely candidate material. As indicated in the stress analysis section (Paragraph 2.4.2), 7075-T651 aluminum extruded bar-stock was the final material choice. The impeller design was reviewed by manufacturing engineering for castability. If stress levels could be reduced and aerodynamic profile tolerances relaxed, an impeller of this size could easily be cast in aluminum alloy 356-T6 or KO1-T6.

The impeller could also be cast in a steel alloy, such as 17-4PH, using normal investment casting techniques.

2.4.4 Turbocharger Modifications for Test Rig

Several turbocharger modifications were necessary in order to use the bearing system and turbine wheel for the compressor test rig drive. The bearing center housing was machined slightly to true the diffuser mounting face and pilot diameter with respect to the bearing bore. Sleeve bearing fits were modified to reduce total radial clearance from 0.0035-in. to 0.0025-in. The thrust collar axial length was reduced to align the impeller discharge with the

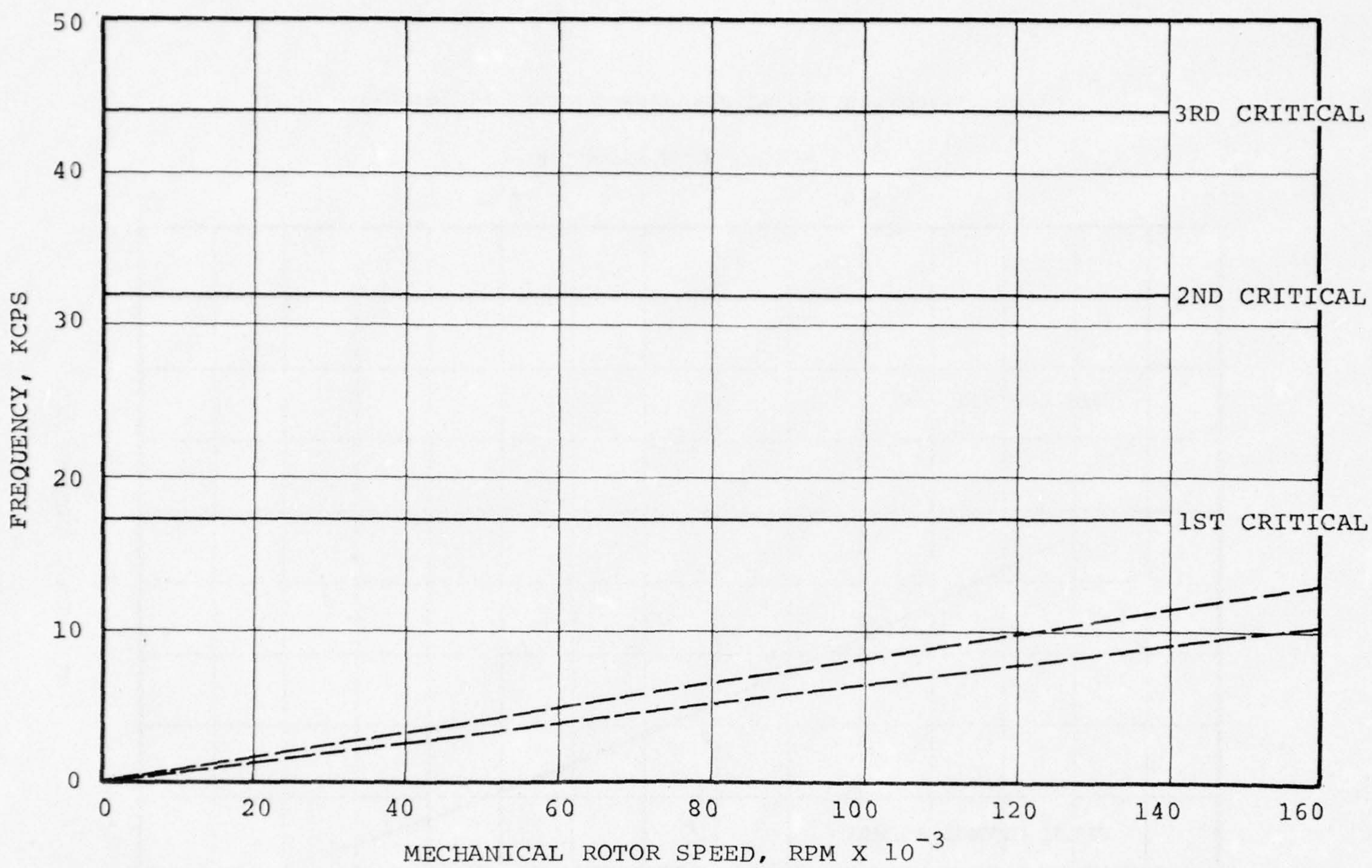


Figure 34. Impeller Blade Vibration Analysis Results.

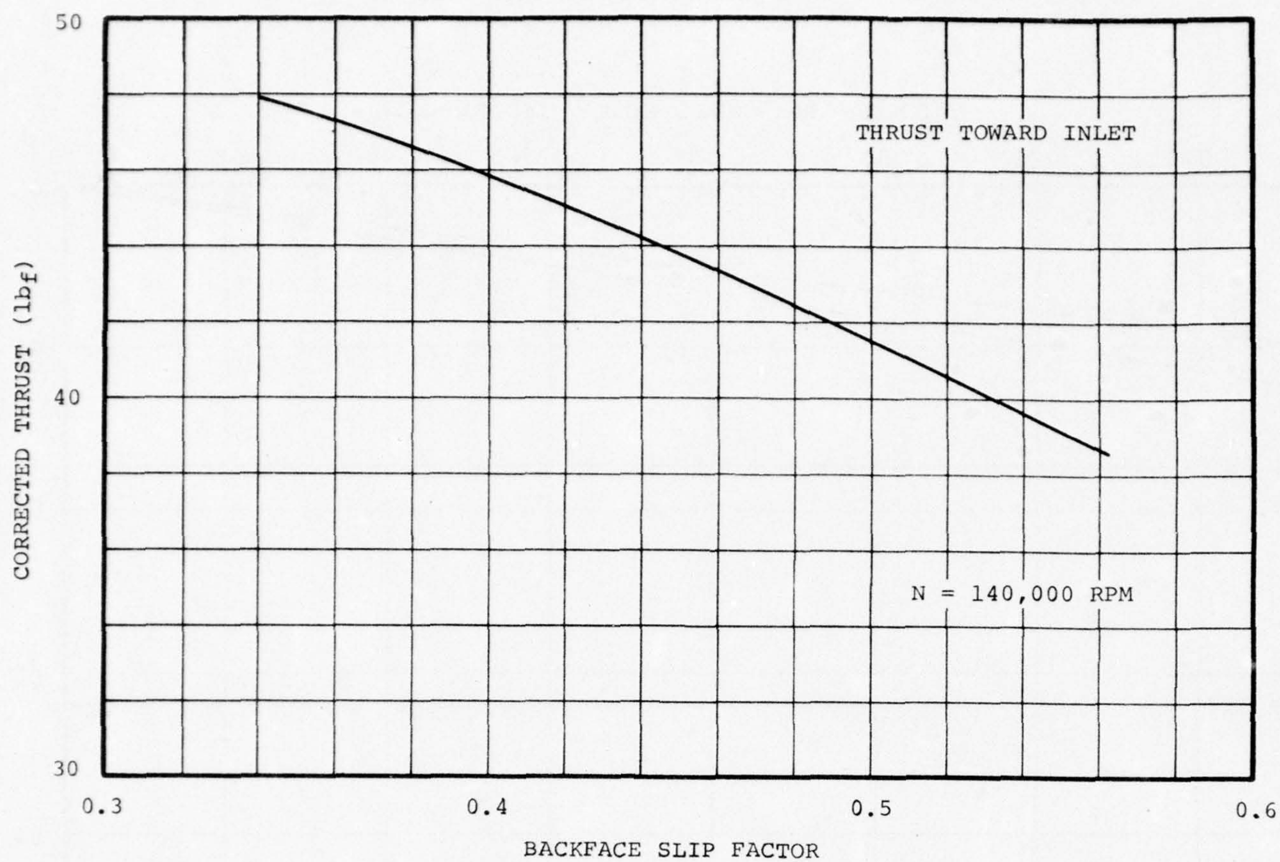


Figure 35. 3 kW Compressor Thrust Estimate.

diffuser inlet (accomplished during initial trial assembly). A pressure tap was provided to measure bearing cavity (scavenge) oil pressure.

2.4.5 Test Rig Dynamic Analysis

The turbocharger first and second critical speeds are approximately 20,000 and 50,000 rpm, respectively. These critical speeds are both very well damped by floating journal bearings, so no problems were anticipated. The turbocharger maximum normal operating speed is 132,000 rpm and the third critical speed was estimated to be above 150,000 rpm.

Test impeller mass was approximately the same as the turbocharger impeller so test rig shaft dynamics were expected to be essentially the same as the turbocharger.

2.4.6 Test Rig Stress and Deformation Analysis

To minimize thermal growth problems (primarily axially), 17-4PH corrosion resistant steel was chosen for the collector and compressor shroud. Considering the small size of these parts and the 1/4 in. minimum material thickness, it was decided that there was sufficient strength and rigidity in the design and a detailed stress and deformation analysis was not necessary.

2.4.7 Instrumentation Uncertainty Analysis

The impact of measured parameter errors (pressure, temperature, and speed) on compressor performance parameters appears in Table XII. Pressure measurement transducer size was selected to be consistent with the expected test values and to take advantage of full scale values (FSV) so that measurement errors could be minimized. Selected errors were grouped to yield maximum deviation from the nominal value for each performance parameter. Normal data reduction calculation routines were employed by using the functional relationships listed in Table XII.

Performance parameters that incorporate many measured parameters are subject to large percentage errors. Extensive test experience with instrumentation, data acquisition, and data reduction systems, similar to those used in this program, make possible error confidence factors of 2 percent or less for the performance parameters.

TABLE XII. TABULATION OF MEASUREMENT INACCURACIES

Parameter	Functional Relationship to Measured Parameters	Maximum Deviation of Measured Parameters	Maximum-Minimum* Calculated Values	Mean Deviation Percent
Orifice Weight Flow	$w = f\ (P_3,\ \Delta p,\ T_3)$	$P = \pm 0.5\%$ FSV $\Delta p = \pm 0.5\%$ FSV $T = \pm 2.2°F$	Maximum = 0.178 lb/sec Minimum = 0.160 lb/sec	±5.4
Temperature Rise	$\frac{\Delta T}{T} = f\ (T_1,\ T_2)$	$T = \pm 2.2°F$	Maximum = 0.580 Minimum = 0.558	±1.92
Impeller Total Pressure Ratio Synthesized in velocity diagram program	$\frac{P}{P} = f\ (P_2,\ P_1,\ w,\ T_1,\ T_2,\ rpm,\ A_{eff_2},\ \beta_2')$	$T = \pm 2.2°F$ $P = \pm 0.5\%$ FSV $rpm = \pm 0.5\%$ FSV $w = \pm 6.2\%$	Maximum = 4.215 Minimum = 3.866	±4.32
Impeller Efficiency From relationship of enthalpies	$\eta = f\ (P_1,\ P_2,\ T_1,\ T_2)$	$T = \pm 2.2°F$ $Pr = \pm 0.5\%$ FSV	Maximum = 0.883 Minimum = 0.830	±3.1

*Design goals for impeller used as baseline values.

SYMBOL IDENTIFICATION

Measured Parameters

P_1 - inlet total pressure
P_2 - impeller exit total pressure
P_3 - flow orifice inlet total pressure
Δp - orifice pressure difference
p_2 - impeller exit static pressure
T_1 - inlet total temperature
T_2 - impeller exit total temperature
T_3 - orifice inlet total temperature
rpm - impeller rotating speed
FSV - full scale value

w - weight flow
$\frac{\Delta T}{T}$ - normalized temperature rise
$\frac{P}{P}$ - impeller pressure ratio
η - impeller efficiency
A_{eff_2} - impeller exit effective area
β'_2 - impeller relative exit angle

2.5 Test Rig Fabrication and Assembly

2.5.1 Test Rig Fabrication

The test rig was fabricated in accordance with test rig drawings.

2.5.2 Shroud and Impeller Fabrication

A slight contour discrepancy occurred during impeller shroud fabrication. Drawing 3604223 (included in Appendix I) allowed the contour to vary ±0.003 in. from nominal. Nominal rotor shroud and inlet contours are shown in Figure 36. The actual part contour was 0.005 in. from nominal in the knee of the shroud.

The impeller shroud contour (Figure 37) was also discrepant in the same region. Actual deviation from nominal was 0.007 in. maximum and the design tolerance was ±0.003 in. Due to the extremely small size of compressor hardware, it was not practical, within program limitations, to attempt correction to design limits.

2.5.3 Diffuser Fabrication

As discussed in Diffuser Design, Paragraph 2.3.4, the diffuser was a brazed assembly. During the furnace brazing operation, the vane and cover plates were not adequately clamped resulting in an oversized throat width. The diffuser was successfully salvaged by applying a large clamping load and remelting the original braze.

2.6 Compressor Testing

2.6.1 Mechanical Integrity Testing

2.6.1.1 Impeller Integrity

Impeller S/N 1 was spun to 160,000 rpm and impeller S/N 2 to 171,000 rpm in the evacuated spin pit. The spin pit motor bearings failed at 171,000 rpm speed. It was anticipated that 174,000 rpm could be achieved. However, since the maximum speed expected during the aerodynamic test was only 154,000 rpm, rig mechanical check and aerodynamic tests were continued.

2.6.1.2 Test Rig Integrity

The rig mechanical check test rig was assembled in accordance with Drawing 3604262 in the vaneless configuration.

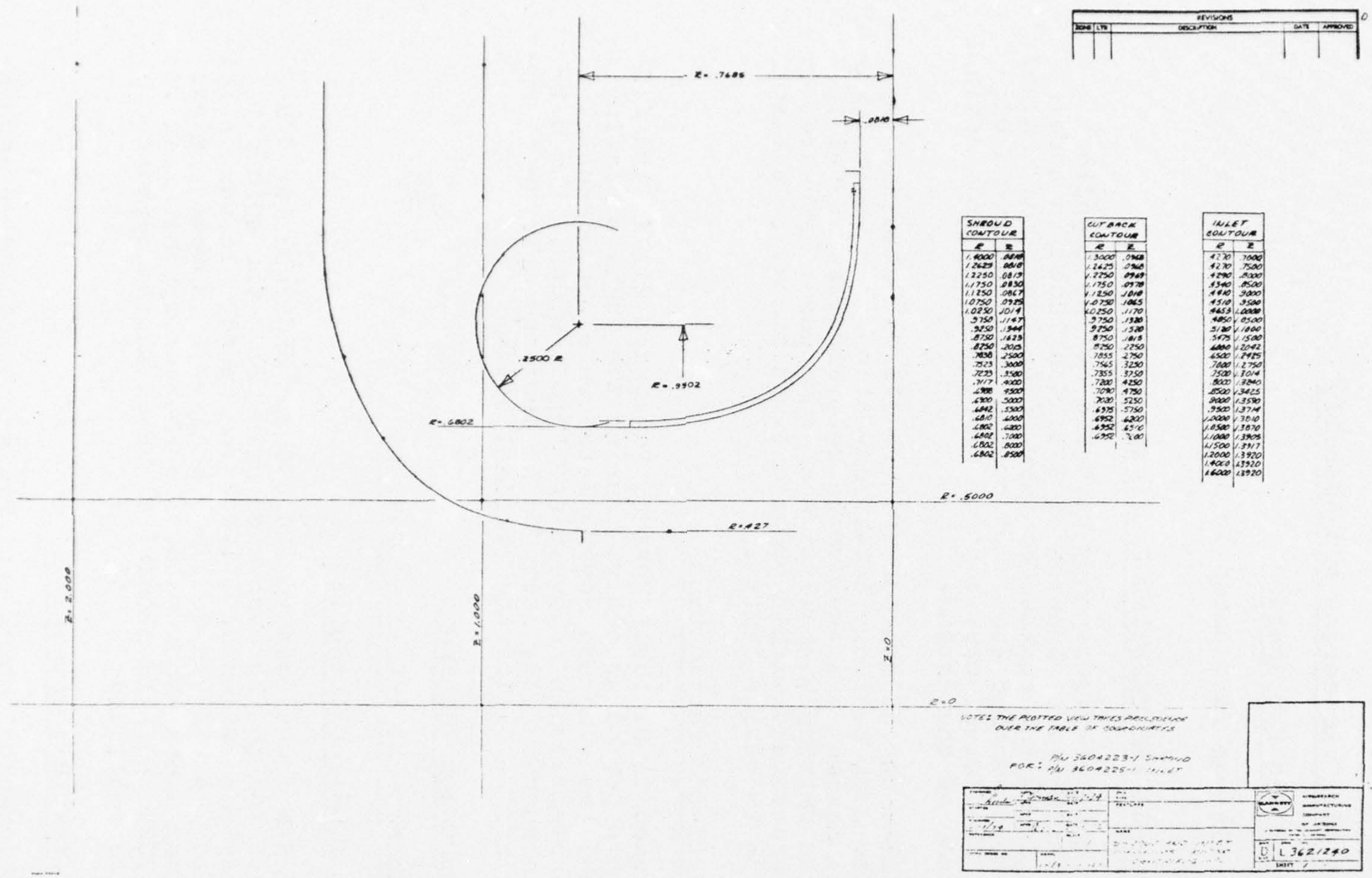


Figure 36. Centrifugal Rotor Shroud and Inlet Contours (Drawing No. L3621240).

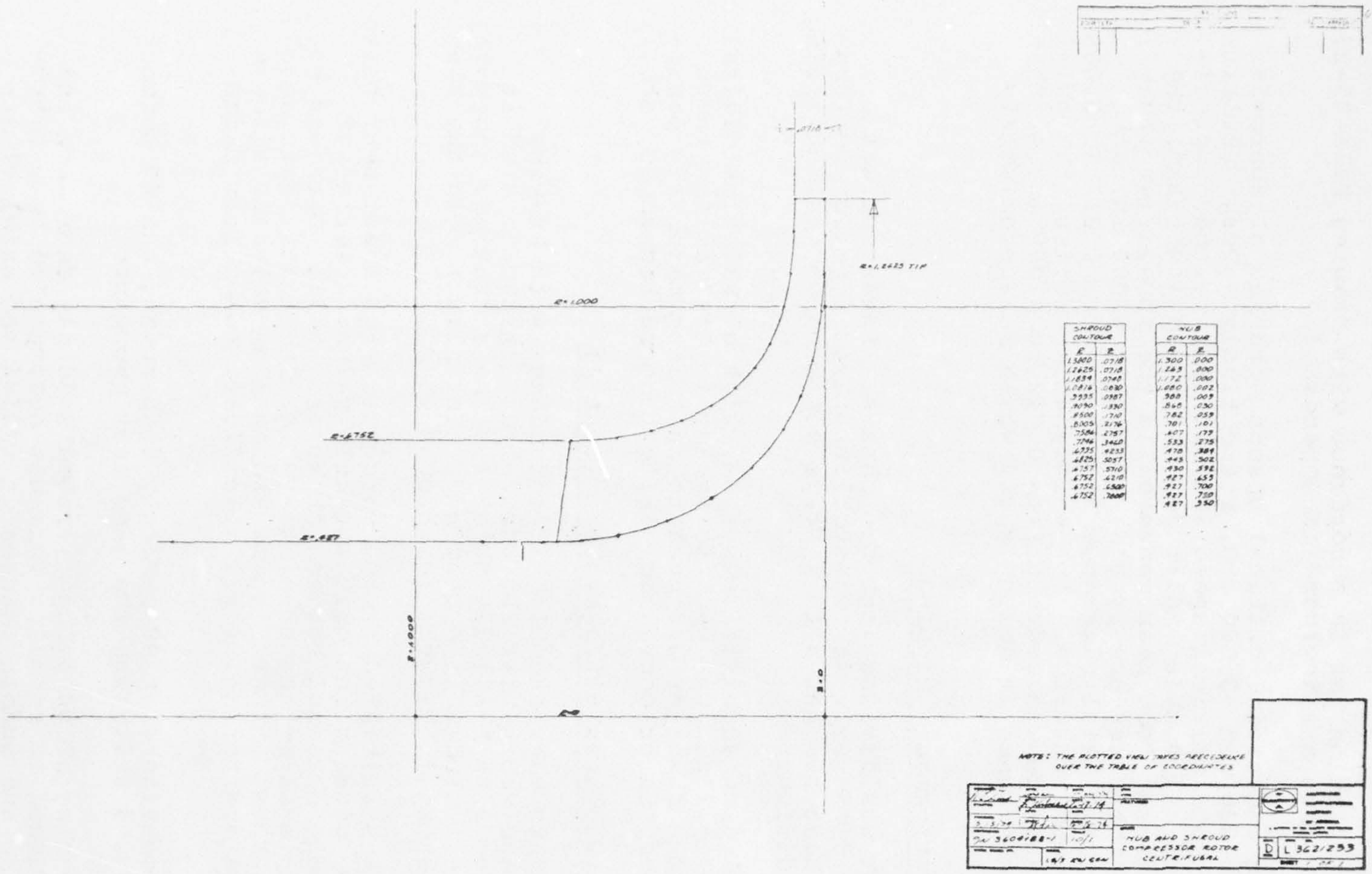


Figure 37. Centrifugal Compressor Rotor Hub and Shroud Contours (Drawing No. L3621233)

Test installation was in accordance with Drawing P47A-05-27. These drawings are included in Appendix I.

The first and second critical speeds occurred at approximately 20,000 and 50,000 rpm, respectively. Peak vibration at the second critical speed (50,000 rpm) reached approximately 0.3 mil double amplitude. As speed increased, the impeller moved from near centered in the shroud (as indicated by the clearance probes) to within 0.004 in. at 140,000 rpm. Axial clearance decreased from 0.011 to 0.009 in. as speed increased. For aerodynamic testing, the axial build clearance was reduced from 0.012 to 0.008 in. so that running clearance at design speed would be approximately 0.005 in.

2.6.2 Performance Mapping

This task was divided into two phases. Phase one was a vaneless diffuser test to establish basic impeller performance. Phase two was a full stage performance test utilizing a vaned diffuser.

A digital data acquisition system, with a real time digital computer on line, was used to assist in controlling these tests. The computer was used to calculate major rig parameters (compressor corrected airflow, corrected speed, etc.).

2.6.2.1 Vaneless Diffuser Test (Test 1)

The test rig was assembled in accordance with Drawing 3604262 and Parts List PL3604262-1 and instrumentated in accordance with L3621282, Sheet 1. These drawings and parts lists are included in Appendix I. Installation in the test cell is shown in Figures 38 through 42.

Testing was initiated at 100 percent design speed near choke flow. By closing the exit throttle valve, a series of points were obtained between choke and stall. Data was recorded at each of these points using the digital data acquisition system. A CRT display and on line computer allowed real time monitoring of all significant compressor parameters.

Testing continued at 90 percent, 80 percent, and 60 percent design speed utilizing the same test procedure.

While running at 60 percent, speed suddenly decreased and then returned to normal. This was accompanied by a vibration spike and sudden changes in radial and axial clearances. The test was terminated to preclude any damage to

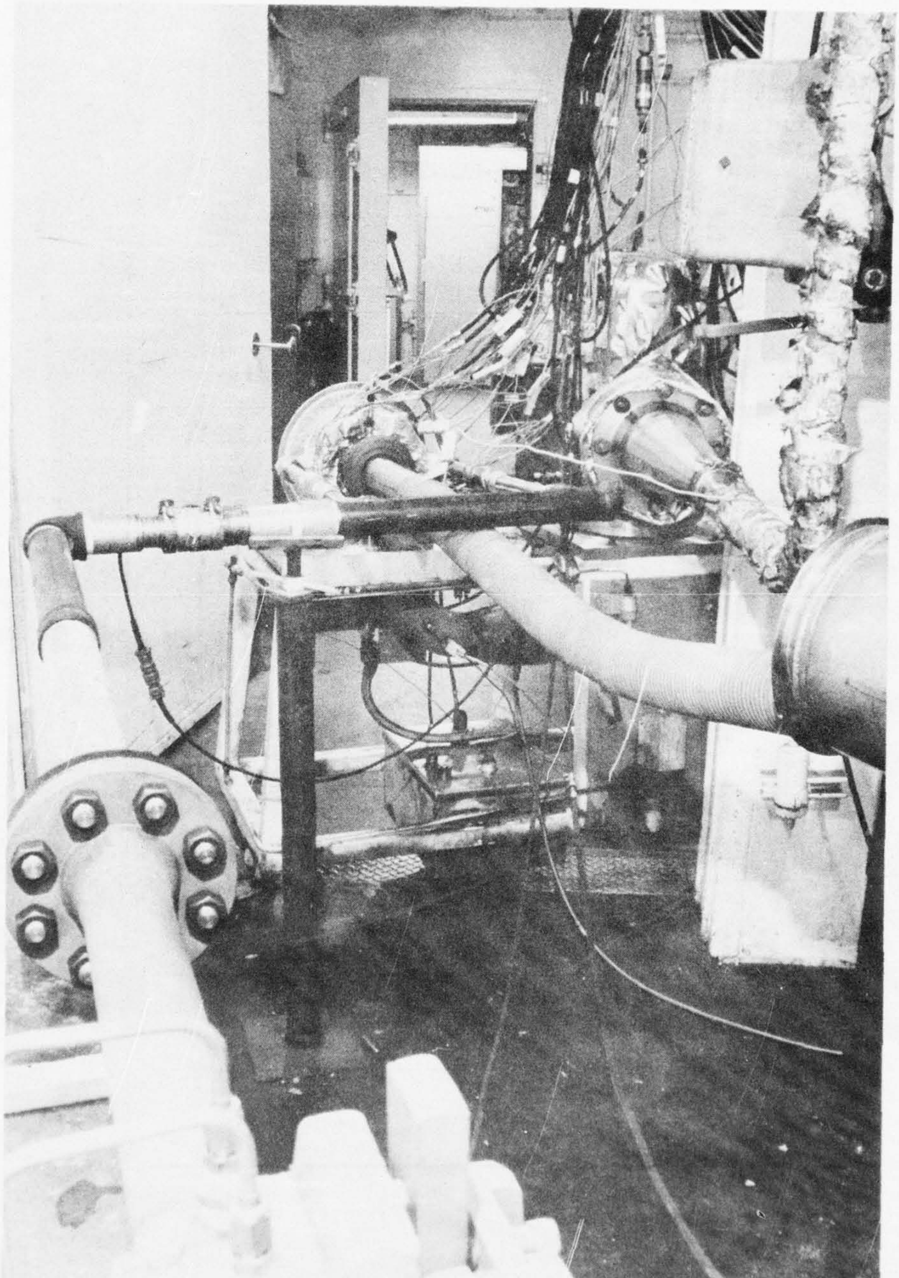


Figure 38. Vaneless Diffuser Test Setup.

MP-52436

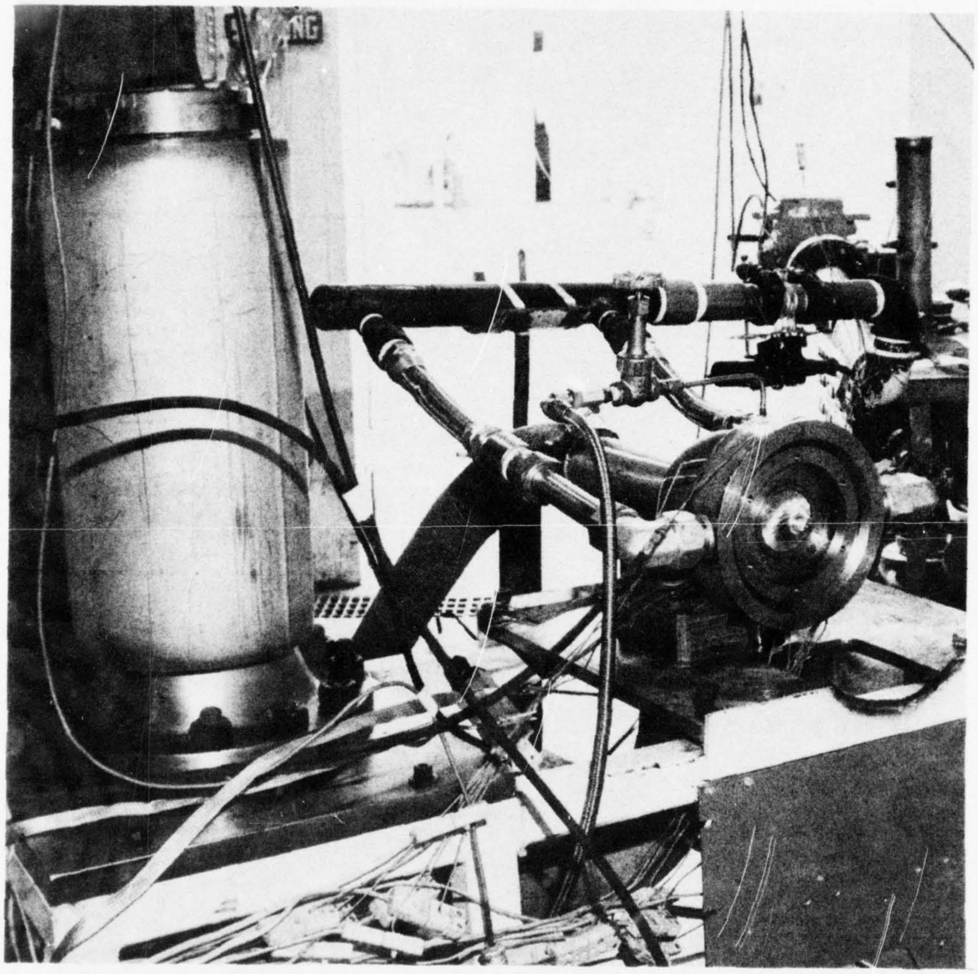


Figure 39. Vaneless Diffuser Test Setup.

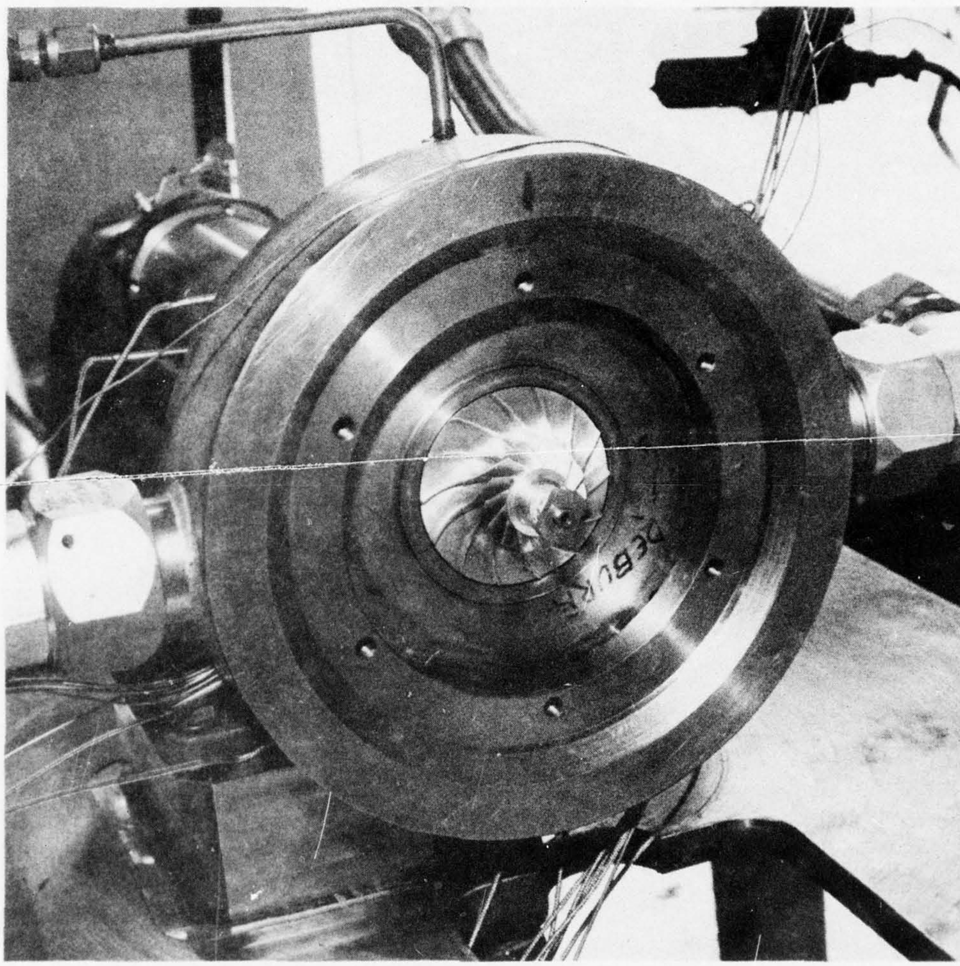


Figure 40. Vaneless Diffuser Test Setup.

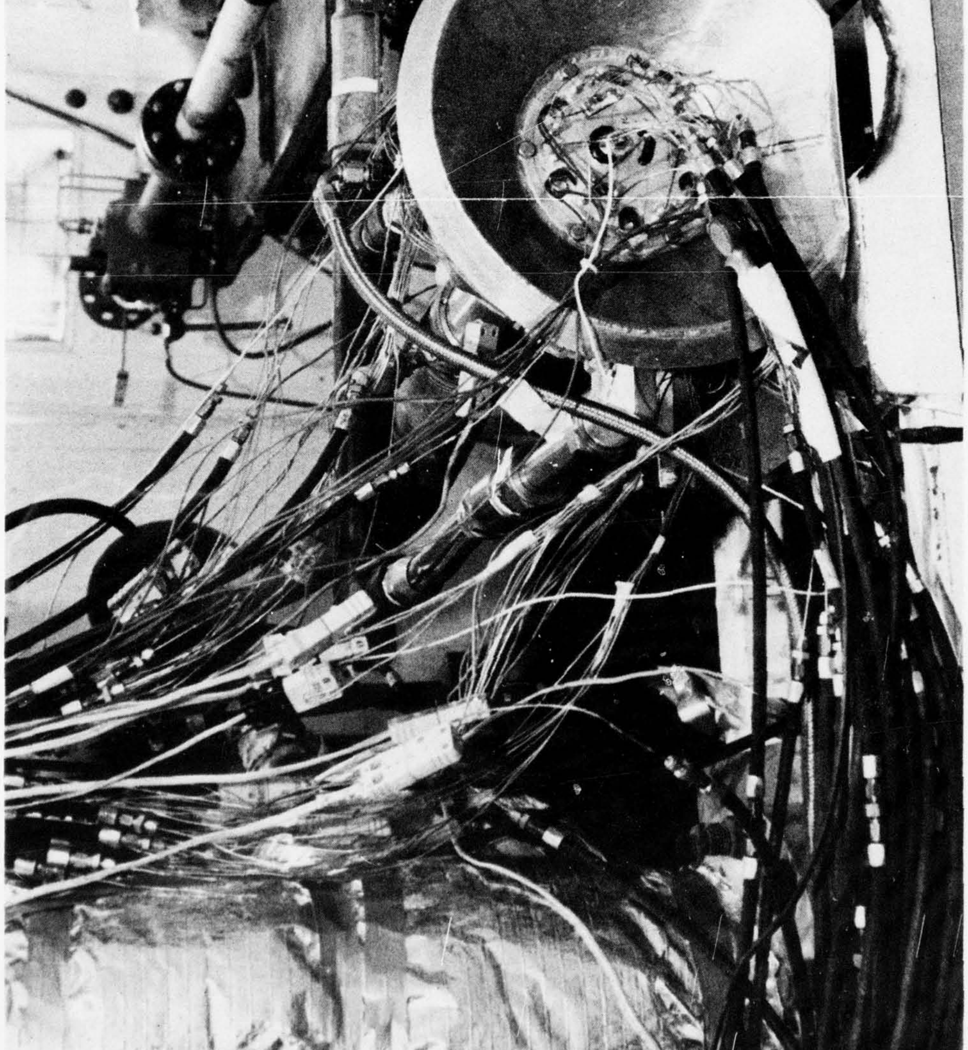


Figure 41. Vaneless Diffuser Test Setup.

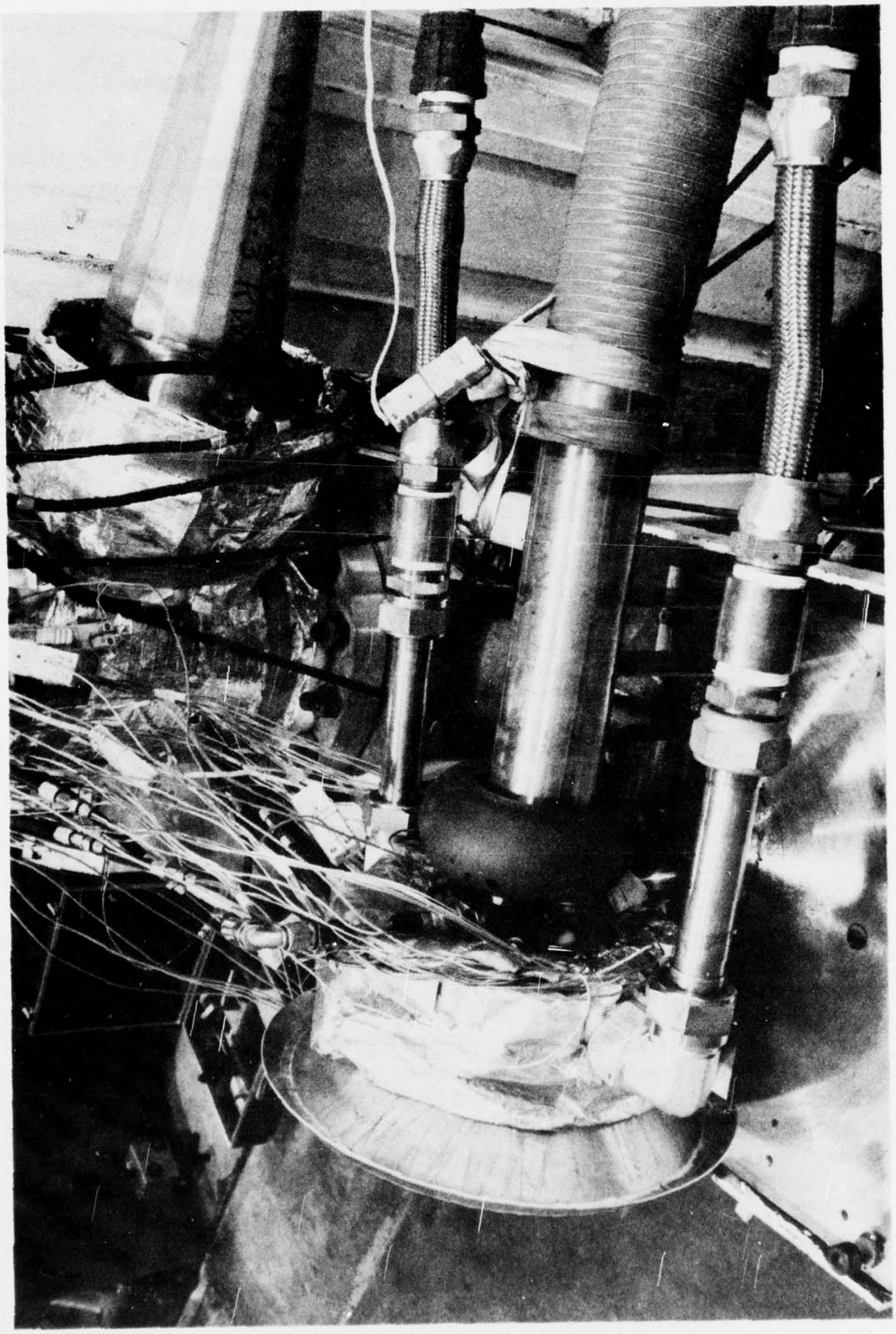


Figure 42. Vaneless Diffuser Test Setup.

the unit. Subsequent disassembly revealed that the probable cause of this anomaly was foreign matter (machining chips) passing through the drive turbine. A slight radial compressor rub was noted in the inducer region; however, damage was limited by the shroud abradable coating to slight surface burnishing.

At this time, the test program was stopped to evaluate aerodynamic test data. Subsequently, it was determined that no other damage had occurred to the test rig.

2.6.2.2 Full Stage Performance (Test 2-3)

The compressor stage performance was rated at the vaned diffuser exit plane. Total pressure and static pressure instrumentation was monitored circumferentially at the vaned diffuser exit to establish an average level of performance since air exiting the rig through two collector pipes resulted in a somewhat non-uniform circumferential pressure distribution at the vaned diffuser exit. Performance maps for the stage test reflect this average performance level.

The vaned diffuser exit plane was chosen as the compressor stage performance rating plane due to lack of a final engine configuration for this unit. By determining the impeller and vaned diffuser performance only, any vaneless space (with associated losses) required for an engine configuration can be analyzed to yield the overall compressor performance. Therefore, flexibility to utilize the impeller and vaned diffuser in various envelopes with a resultant accurate prediction of overall compressor performance was provided by utilizing the vaned diffuser exit as the compressor stage performance rating station.

For the full stage compressor test, a vibration monitoring/recording system was installed. This system indicated a test rig system structural resonance at 138,000 rpm, with an amplitude of approximately 0.1 mil, as the only significant system resonance. Rig operation at close axial clearances (0.002 axial) required a low speed warm up at about 70 percent speed prior to full speed operation. This time (approximately 5 minutes) at low speed effectively stabilized thermal gradients and provided stable clearance throughout the test operating range.

3. DISCUSSION OF TEST RESULTS

3.1 Vaneless Diffuser Test Results

Data was reduced using impeller exit static pressures, total temperatures, mass flow, and speed to synthesize total pressure ratio values for the impeller. Flow and work input values were measured directly. The inlet rating station is located at the origin of the radially in-flowing annulus upstream of the impeller. Therefore, any loss generated in that annulus is charged to the impeller. Test Log pages and manually recorded Data Sheets maintained during vaneless diffuser testing (Test 1) are included in Appendix I.

A compressor map, resulting from this data reduction procedure, is shown in Figure 43. Impeller efficiency, work input, and total pressure ratio design objective values are shown superimposed for comparison. At the design flow, the work input was 3.3 percent low, the impeller pressure ratio 5.7 percent low, and impeller adiabatic efficiency was 1.2 percentage points low.

Factors causing the low work input shown in Figure 43 are:

(A) For manufacturing considerations, one blade was removed from the directly scaled impeller. For the 1.5/3 kW compressor, reducing the blade number from 15 to 14 results in an estimated decrease in slip factor and work input of 0.8 percent.

(B) The location of exit total temperature probes and the fact that the compressor rig was not insulated for the impeller-vaneless diffuser test could have affected measurement accuracy of work input. A rudimentary heat transfer analysis, utilizing measured metal temperatures, indicated that the measured impeller exit stagnation temperature could be approximately 5°F lower than actual temperature at the design objective corrected flow. Therefore, measured work input level could be 1.7 percent low.

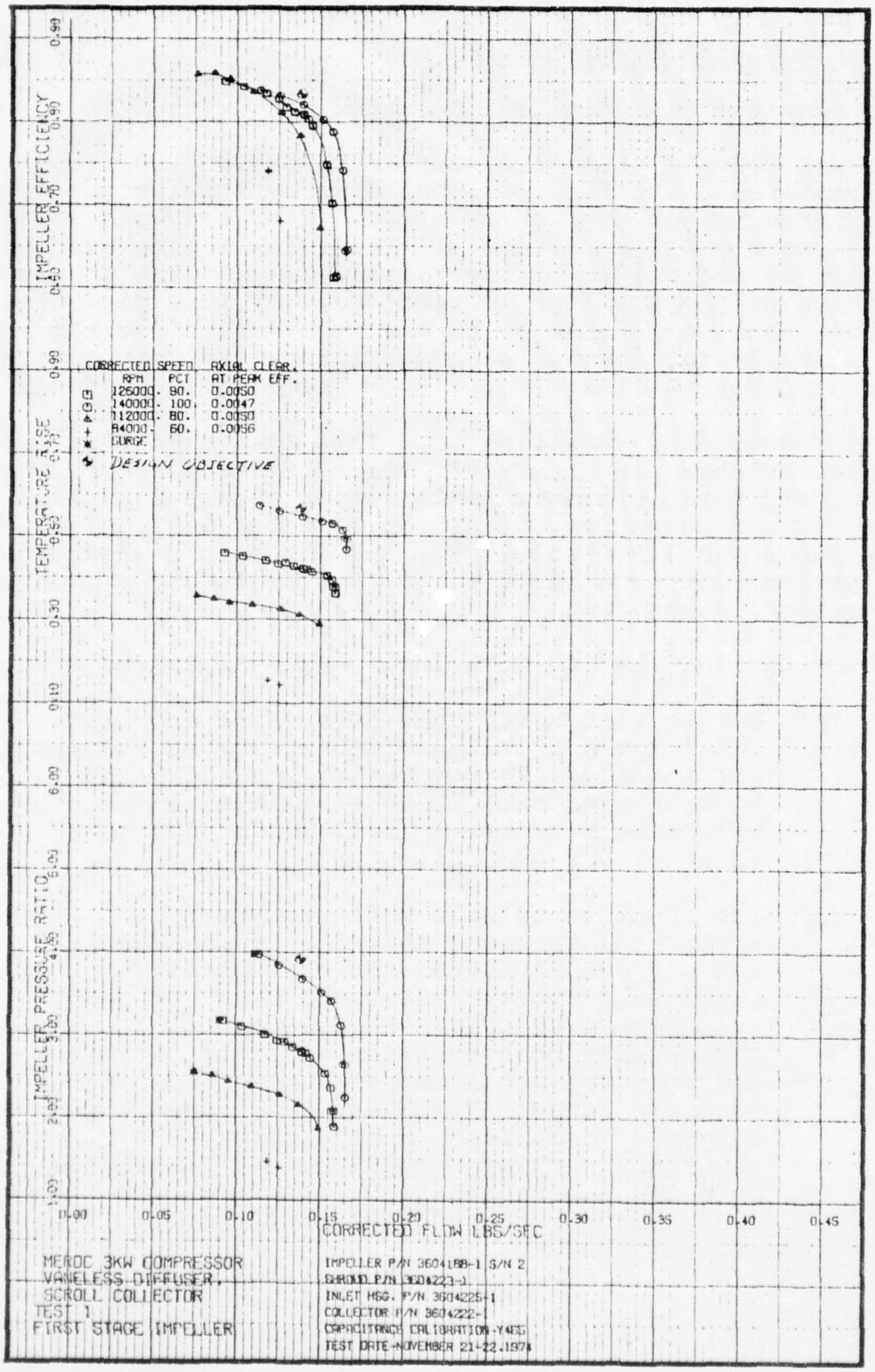


Figure 43. Vaneless Diffuser Test Results (Test 1).

Clearances during this test held fairly constant at 0.005 to 0.006 in. axially and 0.006 to 0.007 in. radially. Estimated compressor performance was based on an axial clearance of 0.002 in. and a radial clearance of 0.005 in. From Figure 12, the predicted stage adiabatic efficiency, based on the 0.005 in. axial clearance and 0.006 in. radial clearance (values for the majority of data points), is 72.5 percent versus 75 percent adiabatic efficiency for baseline clearance levels. Therefore, the impeller efficiency decrement could be due to excessive clearance. Other factors contributing to lower performance may be the impeller and shroud manufacturing deviations from nominal dimen-sions as discussed in Paragraph 2.6.1, and the quantity of inlet instrumentation required for performance evaluation (Reference Instrumentation Drawing L3621282 included in Appendix I).

After completing data analysis, the measured level of impeller performance seemed consistent with program objectives and it did not appear necessary to accumulate any additional impeller data before proceeding with the vaned diffuser design.

In support of the vaned diffuser design, the effect of impeller exit aerodynamic blockage on impeller exit flow conditions was investigated. Data was reduced for impeller exit effective area levels of 90, 85, and 80 percent. Figure 44 shows the effect of impeller exit blockage on impeller exit flow conditions for a data scan near the design objective flow rate. It can be seen from Figure 44 that impeller exit flow angle is particularly sensitive to assumed values of impeller exit effective area. As discussed in Paragraph 2.3.4, this analysis was used for the vaned diffuser design.

3.2 Compressor Stage Test Results and Discussion

Table XIII compares program goals and test data for salient parameters of overall compressor stage performance.

Compressor stage maps are presented, in Figures 45, 46, and 47 for compressor operation with running axial clearance values of 0.0045, 0.0079, and 0.0023 in. and radial clearances of 0.005 to 0.006 in. at design corrected speed. A performance summary for close clearance (0.0023 in. axial clearance) operation is presented in Appendix I.

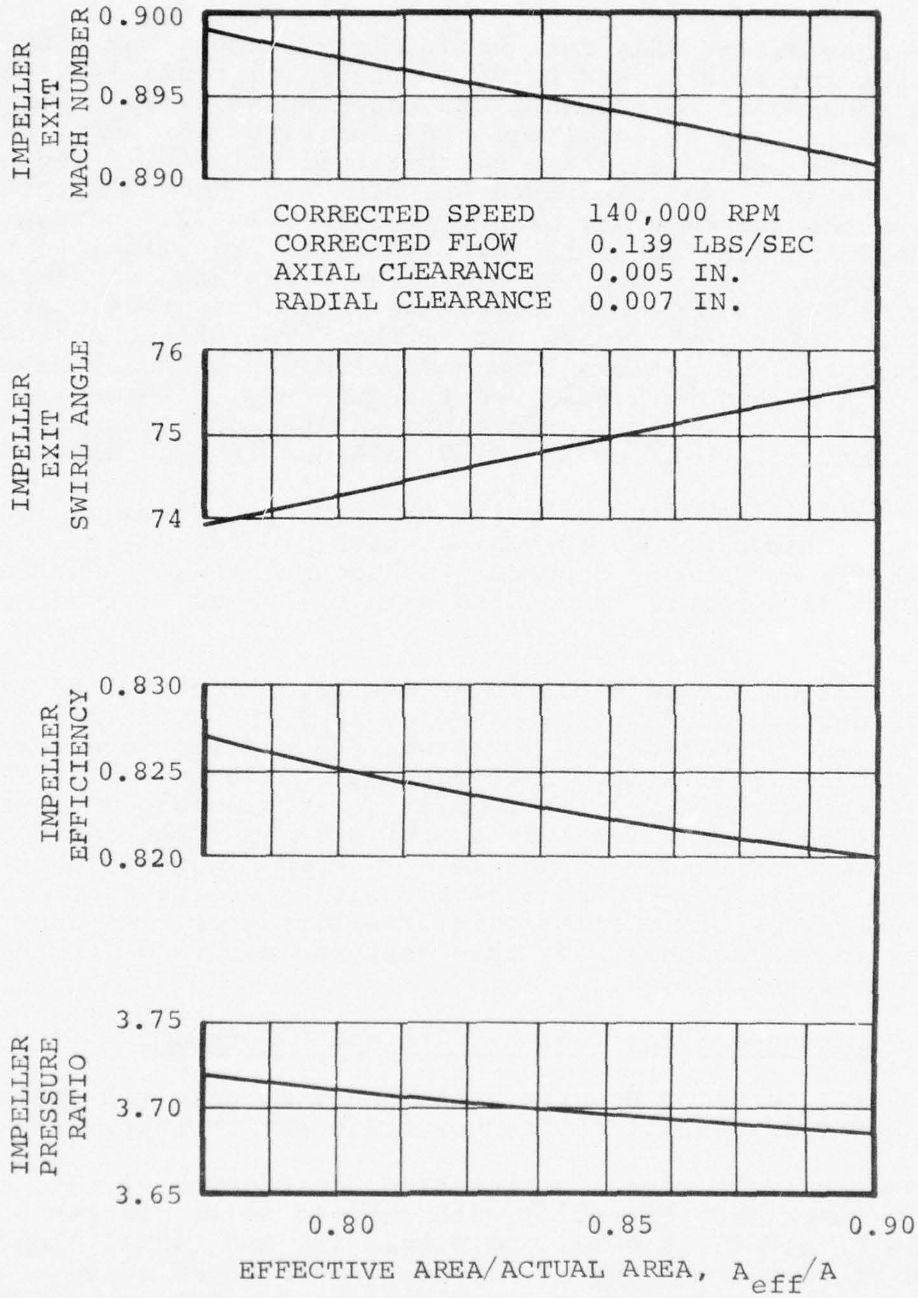


Figure 44. 1.5/3 kW Effective Area Study Using Scan 45 of Test 1.

TABLE XIII. COMPRESSOR STAGE PERFORMANCE PARAMETERS		
	Program Goal	Data (Test 3A)
Peak efficiency (inlet total to diffuser exit total)	0.750	0.746
Pressure ratio at peak efficiency (inlet total to diffuser exit total)	3.50	3.53
Corrected temperature rise $\Delta T/T$ at peak efficiency	0.569	0.578
Corrected mass flow $W\sqrt{\theta}/_{\delta}$ at peak efficiency-lb/s	0.138	0.133
Corrected speed $N/\sqrt{\theta}$ ~ rpm	140,000	140,000
Diffuser exit Mach No. at peak efficiency	0.191	0.205
Axial running clearance at peak efficiency ~ in.	0.002	0.002
Radial running clearance at peak efficiency ~ in.	0.005	0.006

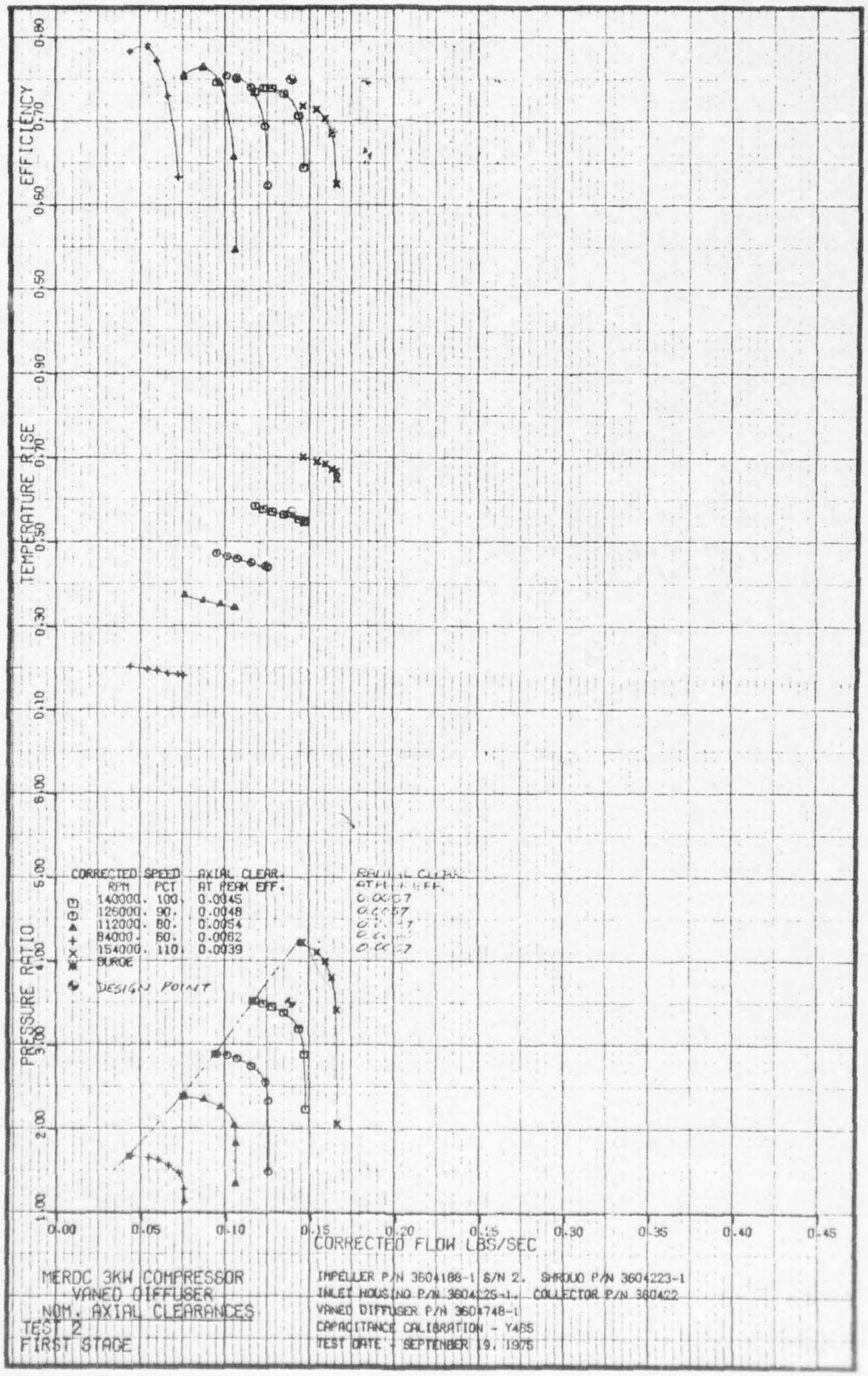


Figure 45. Vaned Diffuser Test Results (Test 2).

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GAS TURBINE COMPRESSOR DEVELOPMENT PROGRAM FOR 1.5/3 KW GENERAT--ETC(U)
DEC 75 J B LEE, E A ZANELLI DAAK02-74-C-0167
UNCLASSIFIED 75-311130 NL

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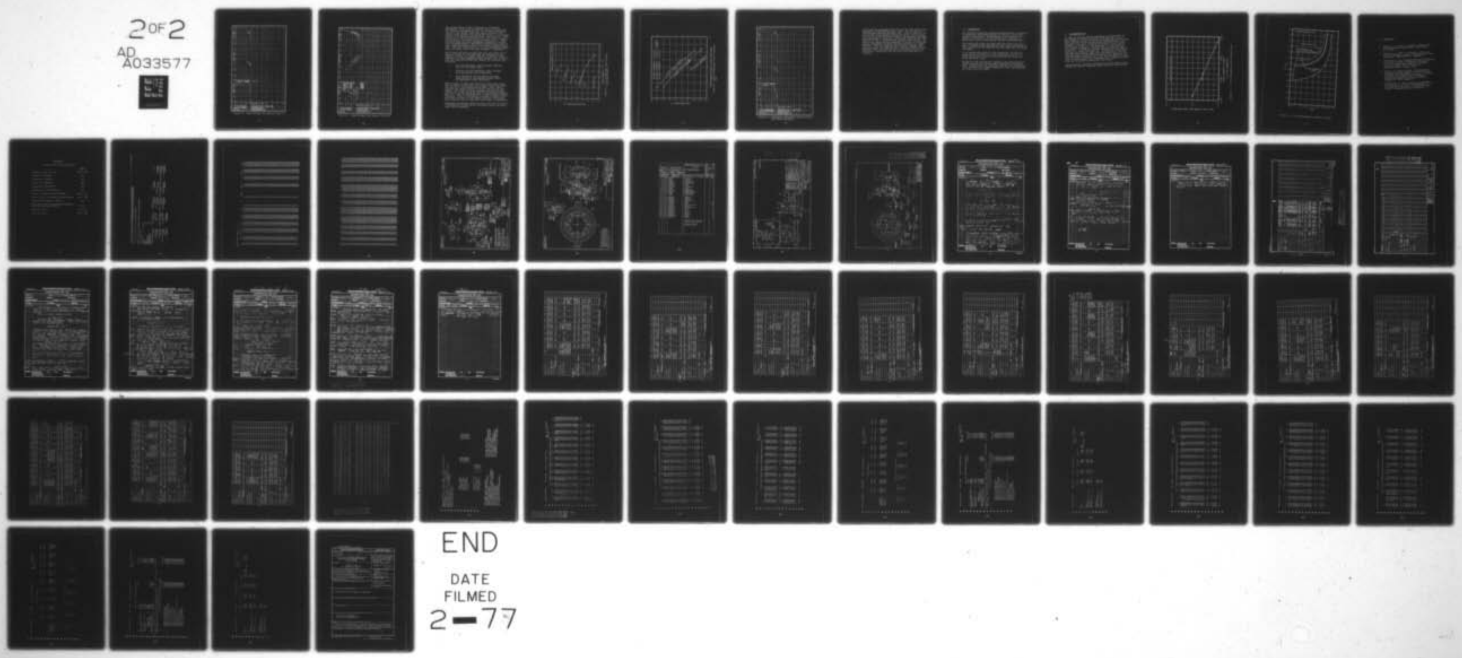

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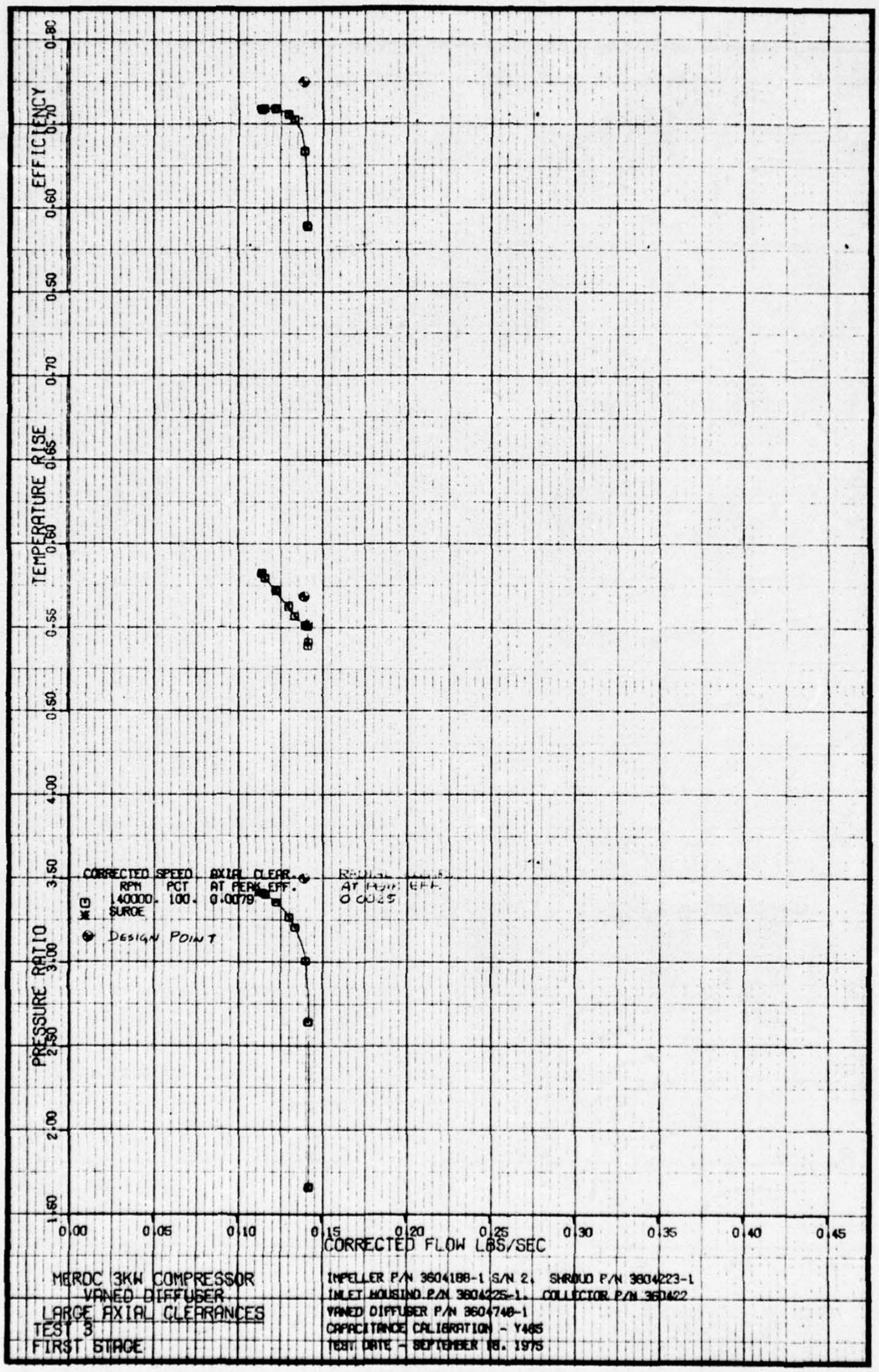

Figure 46. Vaned Diffuser Test Results (Test 3).

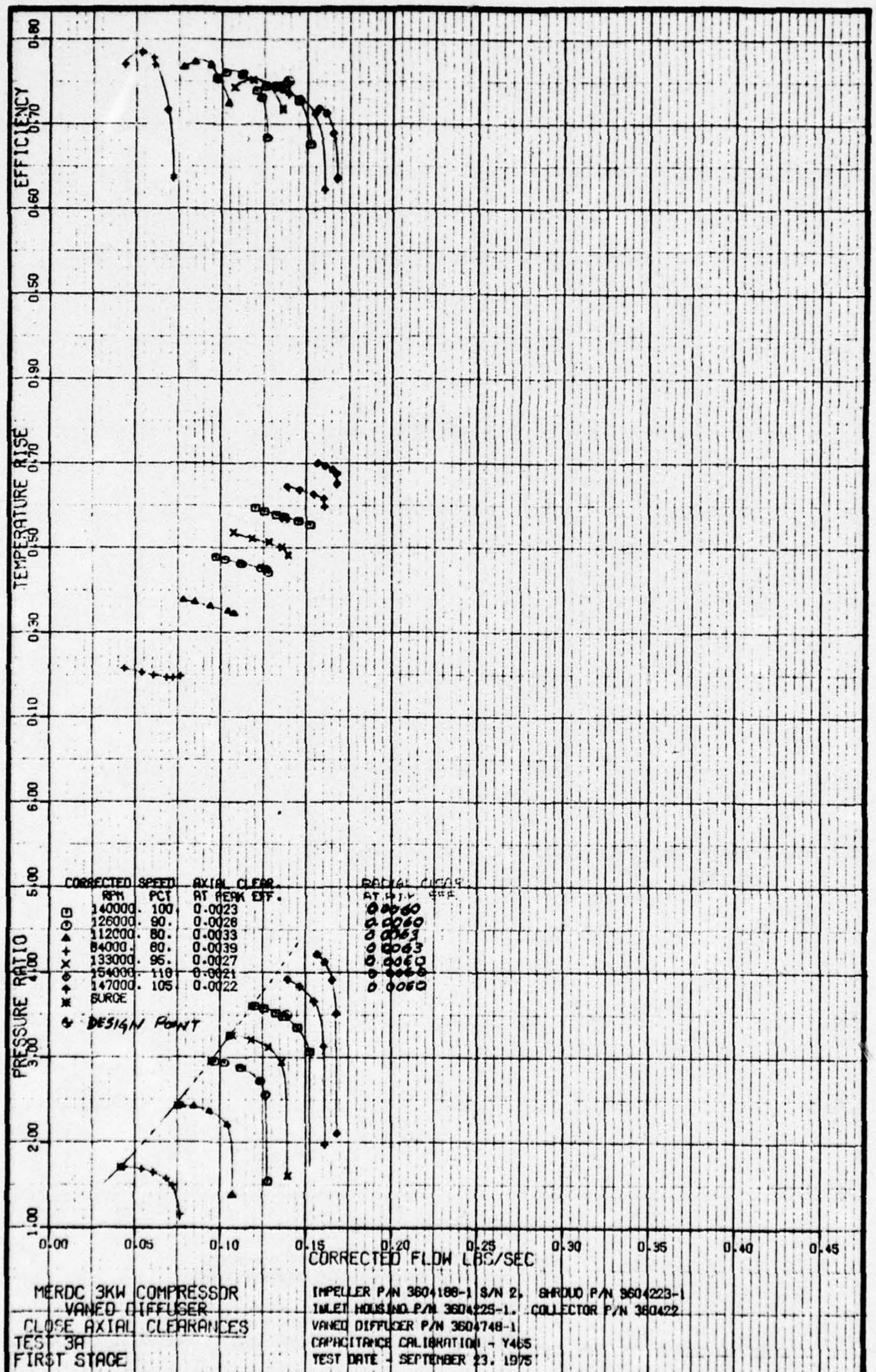

Figure 47. Vaned Diffuser Test Results (Test 3A).

The strong effect of axial clearance on compressor performance can be seen by comparing data in Figures 45, 46, and 47 to the design point. At the design corrected flow of 0.138 lb/sec, with close axial clearance, the overall total-to-total efficiency was within 0.8 percentage points of the design objective value, see Figure 47. Peak efficiency of the stage occurred at a flow of 0.13 lb/sec and was within 0.4 points of the objective value. Representative data scans are presented in Appendix I for design corrected speed at the design corrected flow (Scan 5) and at peak efficiency (Scan 7) for close clearance operation. The test conditions and a listing of measured parameters for Scans 5 and 7 are also included in Appendix I.

The highest efficiency levels were near the surge line as shown in Figure 43. The diffuser was matched with the impeller to favor the higher impeller efficiency levels. Comparing the stage compressor maps (Figures 45, 46 and 47) with the vaneless diffuser map (Figure 43) indicates the following:

- The vaned diffuser limits maximum (choking) flow for all speed lines.
- Choking flow and compressor range increase with decreasing axial clearances.
- Peak efficiency for the design corrected speed occurs at increasingly higher flows for decreasing axial clearances.

The variation of peak stage efficiency with axial clearance is shown in Figure 48, for several speed lines ranging from 60 to 110 percent design speed. This figure indicates the strong effects of axial clearance on efficiency. The effect of axial clearance can be even more significant in the engine because of the probable requirement for a specific pressure ratio to match turbine characteristics. This is illustrated in Figure 49 where clearance data, in terms of peak stage efficiency versus the stage pressure ratio at the peak efficiency, is presented.

Compressor performance based on scroll exit static pressure is presented in Figure 50 for the design speed line with close axial clearances.

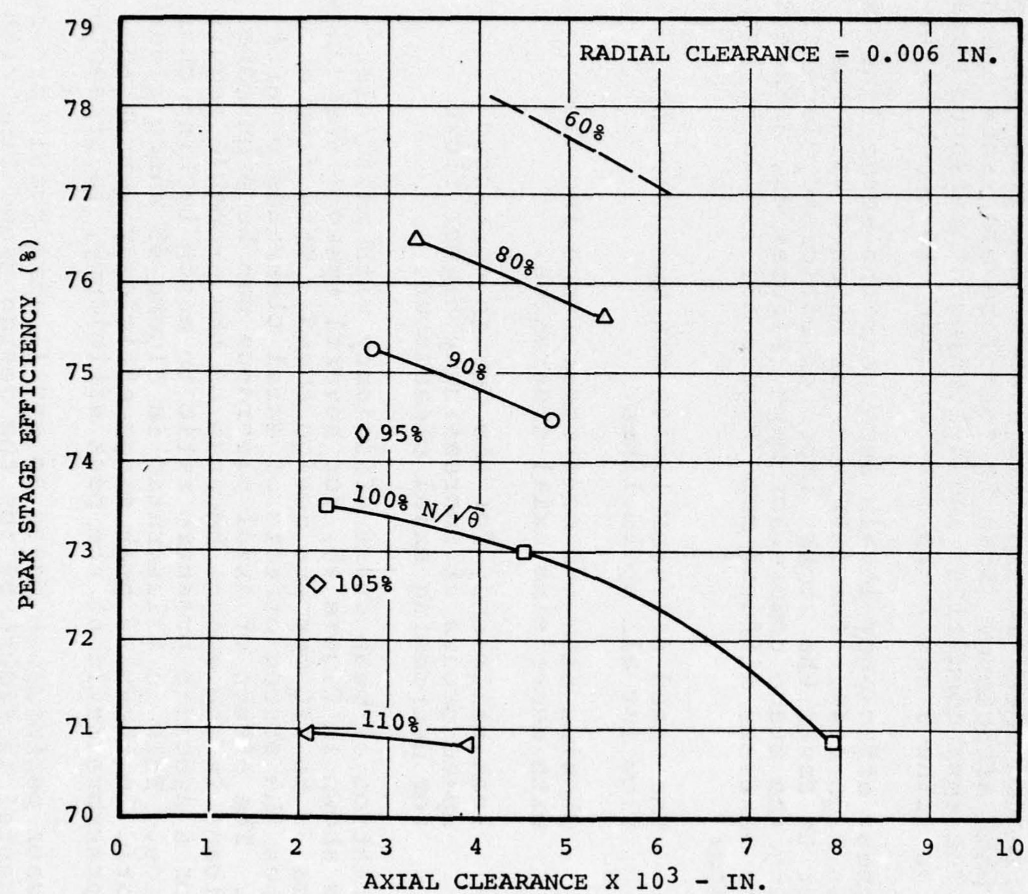

Figure 48. 1.5/3 kW Compressor Axial Clearance Data (Tests 2 and 3).

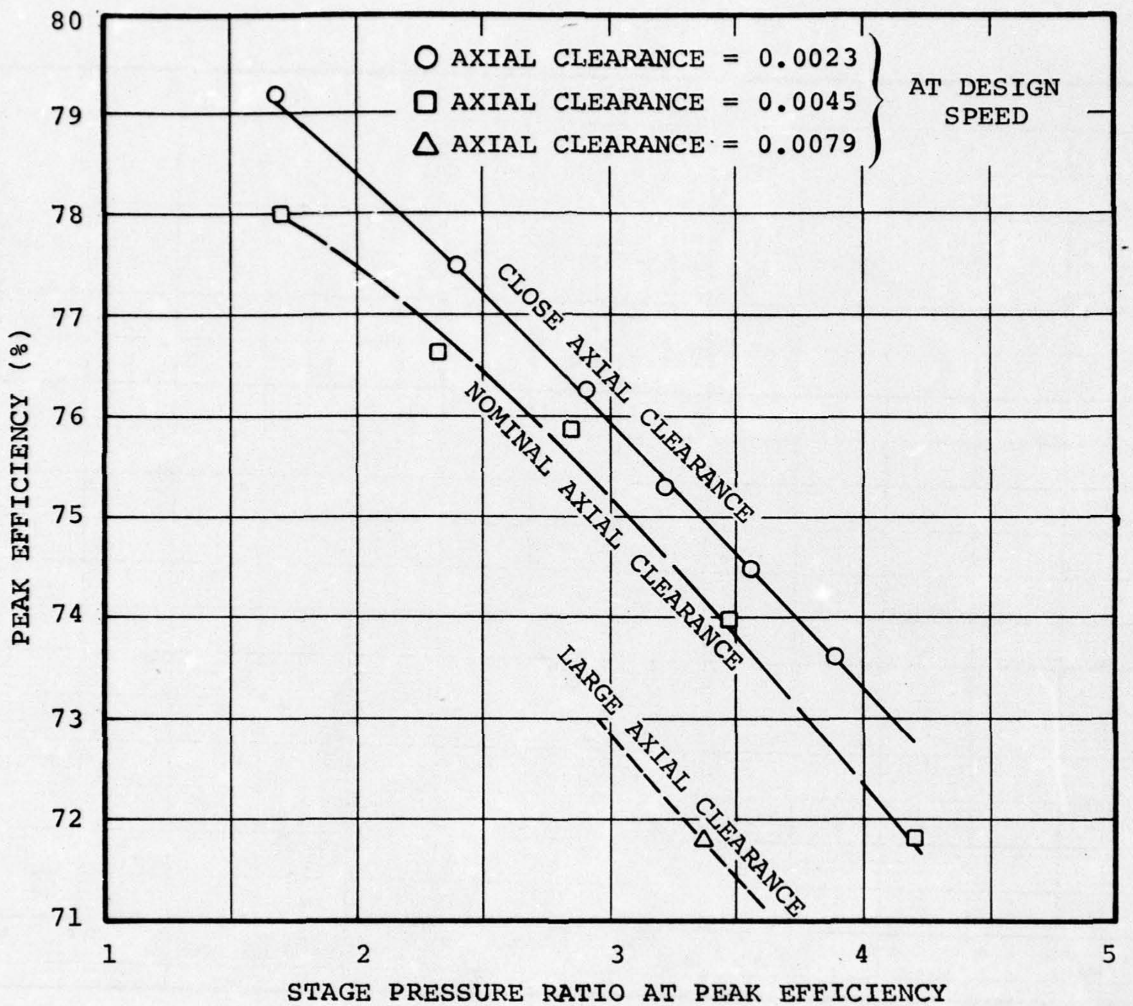

Figure 49. 1.5/3 kW Compressor Axial Clearance Data.

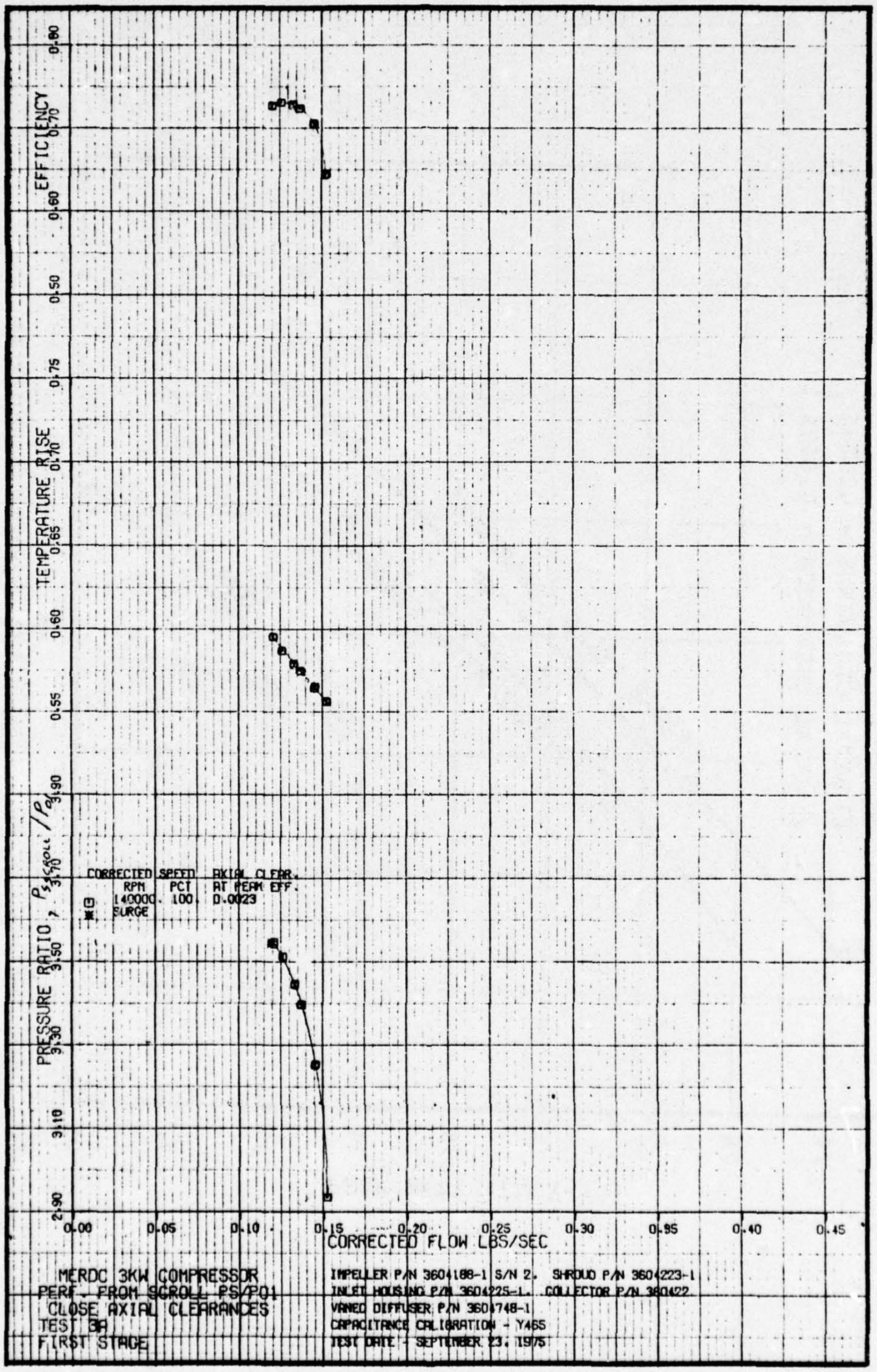

Figure 50. Compressor Performance Based on Scroll Exit Static Pressure.

Insulating the compressor test rig for the full stage tests resulted in higher measured work ($\Delta T/T$) levels than the (uninsulated) vaneless diffuser test. This is seen by comparing work levels between Figures 43 and 45 for the vaneless and stage configurations having approximately the same axial clearances. Although a portion of observed work differences is due to reducing heat transfer from the rig, impeller work input has been observed to change in other compressor development programs with the addition of a vaned diffuser. This is caused by the change in impeller exit static pressure distribution due to diffuser blade loading. Therefore, the true impeller-only work characteristic is difficult to determine, but the full stage test data is reliable.

4.0 CONCLUSIONS

The resultant compressor design presented herein, represents an acceptable aerodynamic design to fulfill 1.5/3 kW gas turbine requirements. Manufacturing considerations for a production configuration may dictate minor redesign to bring rotor stress levels within casting state-of-the-art.

From compressor stage test data obtained during this program, it appears that the diffuser vane angle and throat are well matched with the impeller for providing good efficiency and range.

In an engine application of this compressor, maintaining close (0.002 to 0.004 in.) axial clearances will be an important design criteria to achieve high efficiency and broad operating range.

Analysis of the gear-driven alternator and turboalternator system concepts for meeting power requirements indicated that, although both are acceptable systems, the turboalternator system offers reduced complexity, cost, and generator set frame size and weight.

5. RECOMMENDATIONS

In order to use the current compressor configuration for the assumed 1.5/3 kW gas turbine generator set cycle, a minor impeller shroud recontour is recommended so that peak efficiency will occur at the design corrected flow. For example, if an axial clearance of 0.004 in. and a radial clearance of 0.006 in., are practical for the engine, an 8.7 percent increase in corrected flow is required (see Figure 51). A schematic drawing demonstrating this shroud recontour is shown in Figure 52. In addition to bringing the compressor design speed peak efficiency more in line with the engine design point corrected flow objective, the impeller shroud recontour will also improve impeller clearance to blade height ratio throughout the impeller and will also aid in improving compressor efficiency.

Any additional compressor modification should await future burner and turbine component design and test verification.

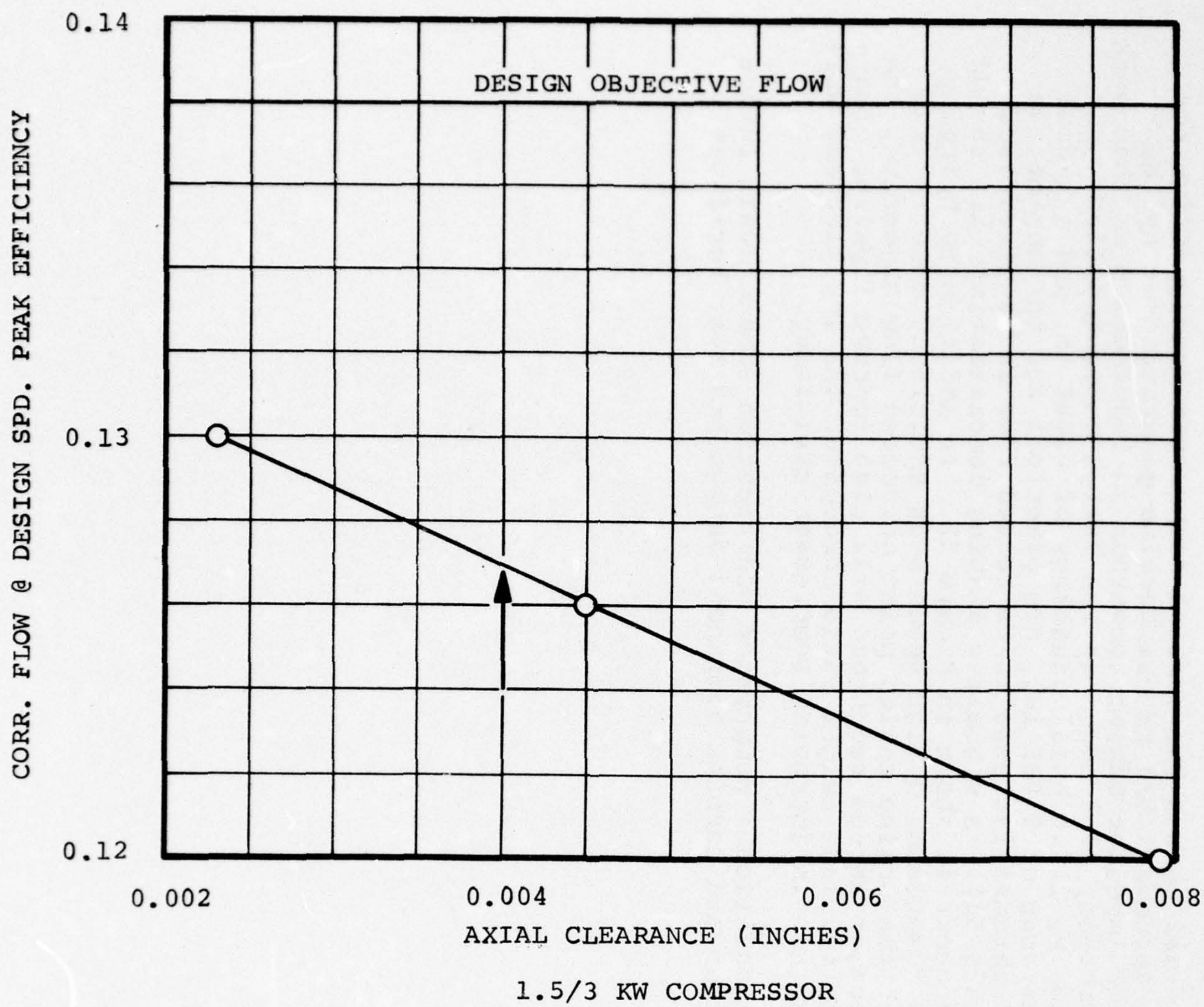

Figure 51. 1.5/3 kW Compressor Axial Clearance Data.

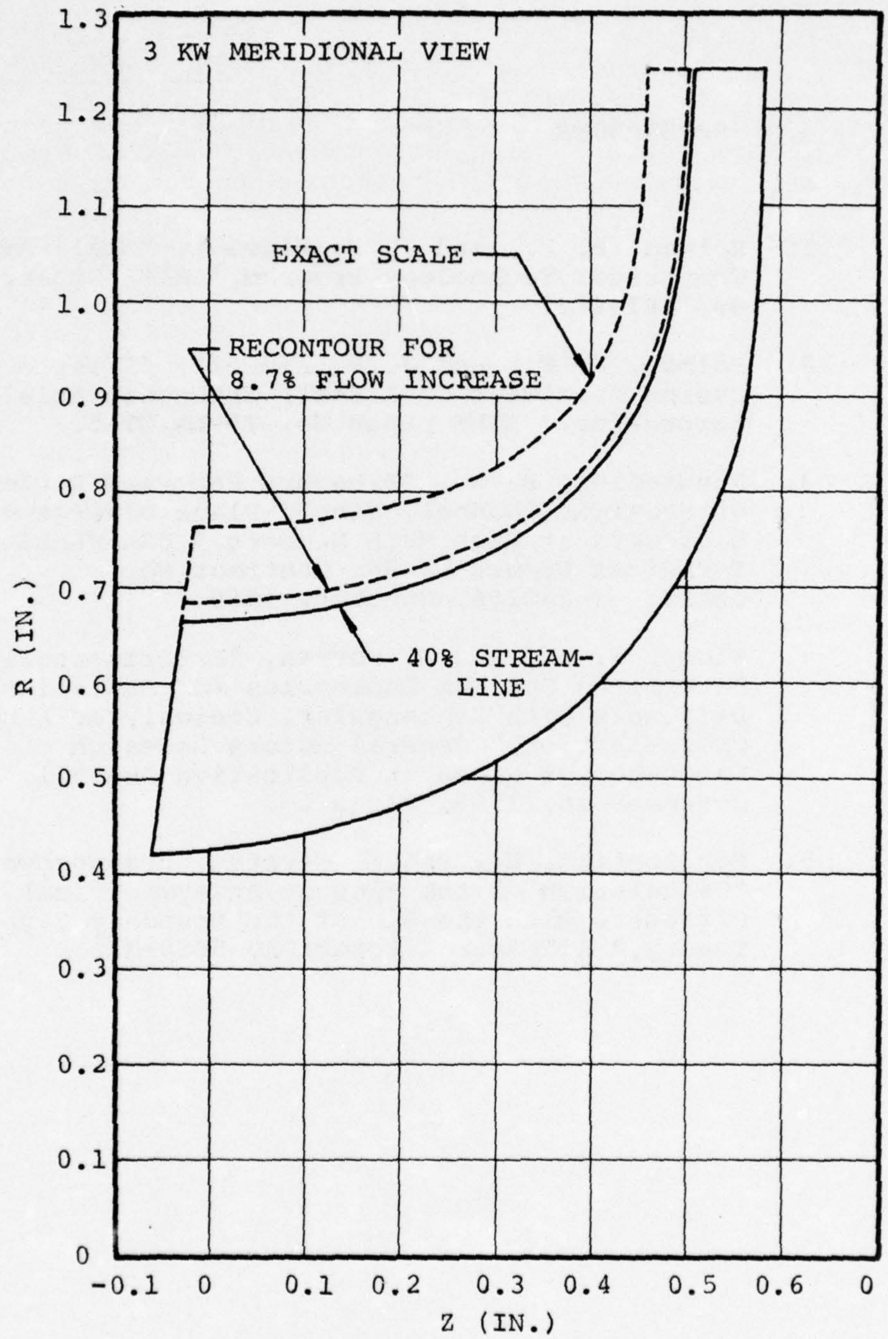

Figure 52. 1.5/3 kW Compressor Impeller Flowpath.

6.0 REFERENCES

1. Holman, F. F., and J. R. Kidwell, "Small Axial Compressor Technology Program," NASA Report No. CR134827.

2. Holman, F. F., and J. R. Kidwell, "Effects of Casing Treatment On A Small Transonic Axial Flow Compressor," ASME paper No. 75-WA/GT-5.

3. Runstadler, P. W., "Pressure Recovery Performance of Straight-Channel, Single-Plane Divergence Diffusers at High Mach Numbers," USAAVLABS Technical Report 69-56, Contract No. DAAJ02-67-C-0106, October, 1969.

4. Klomp, E. D., and G. Sovran, "Experimentally Determined Optimum Geometrics for Rectilinear Diffusers with Rectangular, Conical, or Annular Cross-Section," General Motors Research Laboratories Research Publication GMR-511, November 16, 1965, Pages 6-7.

5. Schlichting, H., and K. Gersten, Braunschweig, "Calculation of the Flow in Axisymmetrical Diffusers with the Aid of the Boundary Layer Theory," AiResearch Report AD-5088-MR.

APPENDIX I

Detailed Data and Information

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$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

TWO DIMENSIONAL BOUNDARY LAYER WITH VARIABLE PROPERTIES

MERDC 3KW DIFFUSER*24 VANES*AREA/=3.0.L/W1=16.7.AS=.92**5/20/75*FINAL

RECTANGULAR DIFFUSER

TABULAR INPUTS      NO. OF POINTS
VELOCITY                  2
WIDTH                     3
RADII                    -0
TEMPERATURE              -0
RECTANGLE WIDTH           3
RECTANGLE HEIGHT          3
ANNULUS DELTA Z          -0

F.S.STAG.SONIC VELOCITY   VISCOSITY TERM C1     VISCOSITY TERM C2     FLOW LENGTH              (L/K)
        .13920E+04              .11560E-04            .74423E+00            .13995E+01      0.

     PRANDTL NUMBER             SHAFT SPEED     F.S. TEMPERATURE     F.S.VELOCITY              F.S. DENSITY
        .68995E+00         -0.                        .71551E+03            .10639E+04            .12220E+00

   F.S. STAG. TEMP.     SPECIFIC HEAT RATIO   INIT. FLAT PLATE F.F.  INIT.MOM.DIS.TH./LENG.  FORM FACTOR TUR.SEPAR.
        .80895E+03              .13955E+01            .14000E+01            -0.                  -.34000E+00

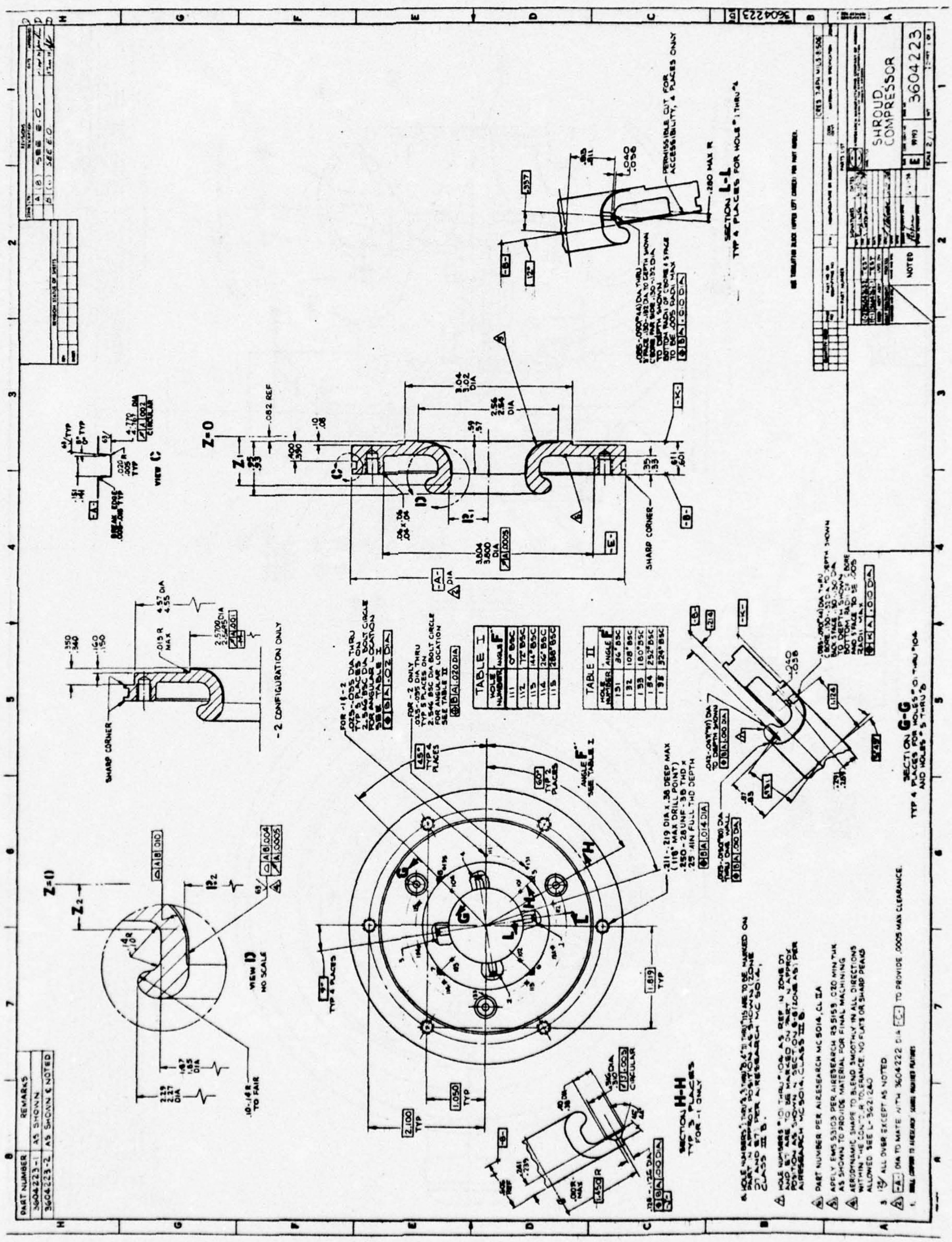
 TOTAL CHANNEL LENGTH     CH. INLET RADIUS      FORM FACTOR CONST.    DAMPING FACTOR, C4       F.S. STAG. PRESS.
        .11663E+00         0.                         .40000E+01            .20000E+00            .49951E+02

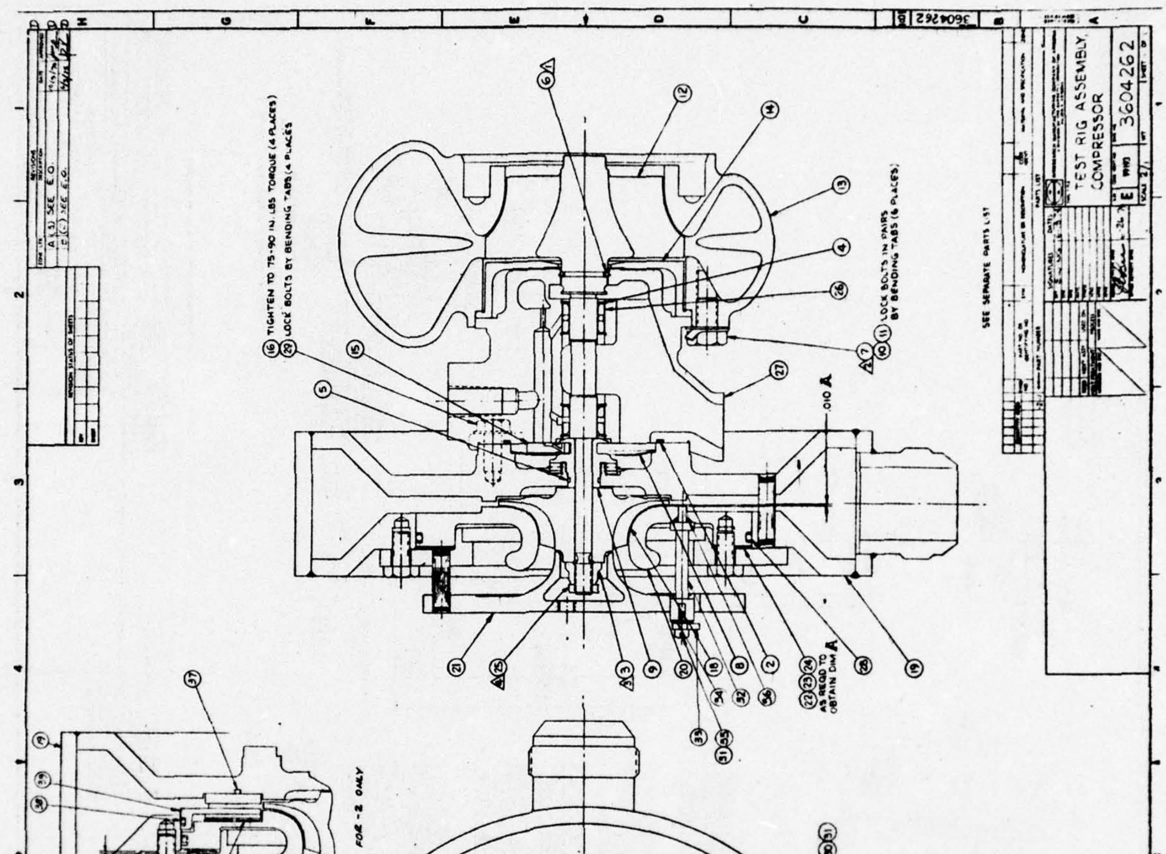
          MASS FLOW        GAS CONSTANT
        .55500E-02              .53349E+02
```

NUMBER OF MAJOR ITERATIONS = 19

X/L	T/TI	RHO/RHOI	TR/TI	HBT	HBAR	HE	RECRIT	WIDTH	B	DELTA Z	PT AVG
0.00	1.0041	1.0104	1.1159	.125969	1.7459	0.	0.	.0638	.0770	0.0000	48.2659
.02	1.0076	1.0194	1.1163	.122047	1.7263	0.	0.	.0855	.0770	0.0000	48.0876
.04	1.0131	1.0334	1.1169	.116000	1.7108	0.	0.	.0872	.0770	0.0000	47.8615
.06	1.0180	1.0461	1.1175	.110672	1.7013	0.	0.	.0888	.0770	0.0000	47.6692
.08	1.0224	1.0577	1.1180	.105809	1.6952	0.	0.	.0905	.0770	0.0000	47.5027
.10	1.0269	1.0695	1.1185	.100939	1.6886	0.	0.	.0924	.0770	0.0000	47.3460
.12	1.0347	1.0900	1.1194	.092712	1.6668	0.	0.	.0959	.0770	0.0000	47.1329
.14	1.0410	1.1070	1.1202	.086043	1.6508	0.	0.	.0994	.0770	0.0000	46.9573
.16	1.0464	1.1215	1.1208	.080477	1.6386	0.	0.	.1030	.0770	0.0000	46.8130
.18	1.0510	1.1340	1.1213	.075734	1.6289	0.	0.	.1065	.0770	0.0000	46.6935
.20	1.0550	1.1450	1.1218	.071630	1.6212	0.	0.	.1100	.0770	0.0000	46.5950
.22	1.0586	1.1548	1.1222	.068033	1.6148	0.	0.	.1136	.0770	0.0000	46.5140
.24	1.0617	1.1636	1.1226	.064850	1.6094	0.	0.	.1171	.0770	0.0000	46.4475
.26	1.0646	1.1715	1.1229	.062008	1.6049	0.	0.	.1206	.0770	0.0000	46.3933
.28	1.0672	1.1786	1.1232	.059452	1.6010	0.	0.	.1242	.0770	0.0000	46.3495
.30	1.0695	1.1851	1.1235	.057138	1.5977	0.	0.	.1277	.0770	0.0000	46.3146
.32	1.0716	1.1911	1.1237	.055032	1.5948	0.	0.	.1312	.0770	0.0000	46.2873
.34	1.0736	1.1967	1.1240	.053105	1.5922	0.	0.	.1348	.0770	0.0000	46.2664
.36	1.0754	1.2018	1.1242	.051335	1.5900	0.	0.	.1383	.0770	0.0000	46.2513
.38	1.0771	1.2065	1.1244	.049701	1.5880	0.	0.	.1418	.0770	0.0000	46.2410
.40	1.0786	1.2109	1.1246	.048188	1.5863	0.	0.	.1454	.0770	0.0000	46.2349
.42	1.0801	1.2150	1.1247	.046783	1.5848	0.	0.	.1489	.0770	0.0000	46.2325
.44	1.0814	1.2189	1.1249	.045473	1.5835	0.	0.	.1524	.0770	0.0000	46.2332
.46	1.0827	1.2225	1.1250	.044248	1.5823	0.	0.	.1560	.0770	0.0000	46.2368
.48	1.0839	1.2259	1.1252	.043101	1.5813	0.	0.	.1595	.0770	0.0000	46.2427
.50	1.0850	1.2291	1.1253	.042023	1.5804	0.	0.	.1631	.0770	0.0000	46.2507
.52	1.0861	1.2321	1.1254	.041009	1.5796	0.	0.	.1666	.0770	0.0000	46.2606
.54	1.0871	1.2350	1.1255	.040051	1.5789	0.	0.	.1701	.0770	0.0000	46.2721
.56	1.0880	1.2377	1.1256	.039147	1.5784	0.	0.	.1737	.0770	0.0000	46.2849
.58	1.0889	1.2403	1.1258	.038290	1.5779	0.	0.	.1772	.0770	0.0000	46.2989
.60	1.0898	1.2428	1.1258	.037478	1.5775	0.	0.	.1807	.0770	0.0000	46.3140
.62	1.0906	1.2451	1.1259	.036706	1.5771	0.	0.	.1843	.0770	0.0000	46.3299
.64	1.0913	1.2473	1.1260	.035971	1.5768	0.	0.	.1878	.0770	0.0000	46.3466
.66	1.0921	1.2495	1.1261	.035272	1.5766	0.	0.	.1913	.0770	0.0000	46.3640
.68	1.0928	1.2515	1.1262	.034604	1.5765	0.	0.	.1949	.0770	0.0000	46.3819
.70	1.0935	1.2535	1.1263	.033967	1.5764	0.	0.	.1984	.0770	0.0000	46.4003
.72	1.0941	1.2553	1.1264	.033357	1.5763	0.	0.	.2019	.0770	0.0000	46.4191
.74	1.0947	1.2571	1.1264	.032773	1.5763	0.	0.	.2055	.0770	0.0000	46.4381
.76	1.0953	1.2588	1.1265	.032214	1.5763	0.	0.	.2090	.0770	0.0000	46.4575
.78	1.0959	1.2605	1.1266	.031677	1.5764	0.	0.	.2125	.0770	0.0000	46.4771
.80	1.0964	1.2621	1.1266	.031162	1.5765	0.	0.	.2161	.0770	0.0000	46.4968
.82	1.0970	1.2636	1.1267	.030666	1.5767	0.	0.	.2196	.0770	0.0000	46.5168
.84	1.0975	1.2651	1.1267	.030190	1.5769	0.	0.	.2231	.0770	0.0000	46.5350
.86	1.0980	1.2665	1.1268	.029731	1.5771	0.	0.	.2267	.0770	0.0000	46.5552
.88	1.0984	1.2679	1.1269	.029288	1.5773	0.	0.	.2302	.0770	0.0000	46.5755
.90	1.0989	1.2692	1.1269	.028861	1.5775	0.	0.	.2337	.0770	0.0000	46.5962
.92	1.0993	1.2705	1.1270	.028449	1.5778	0.	0.	.2373	.0770	0.0000	46.6174
.94	1.0998	1.2718	1.1270	.028050	1.5781	0.	0.	.2408	.0770	0.0000	46.6391
.96	1.1002	1.2730	1.1271	.027665	1.5783	0.	0.	.2443	.0770	0.0000	46.6613
.98	1.1006	1.2742	1.1271	.027291	1.5786	0.	0.	.2479	.0770	0.0000	46.6839
1.00	1.1010	1.2753	1.1272	.026930	1.5789	0.	0.	.2514	.0770	0.0000	46.7064

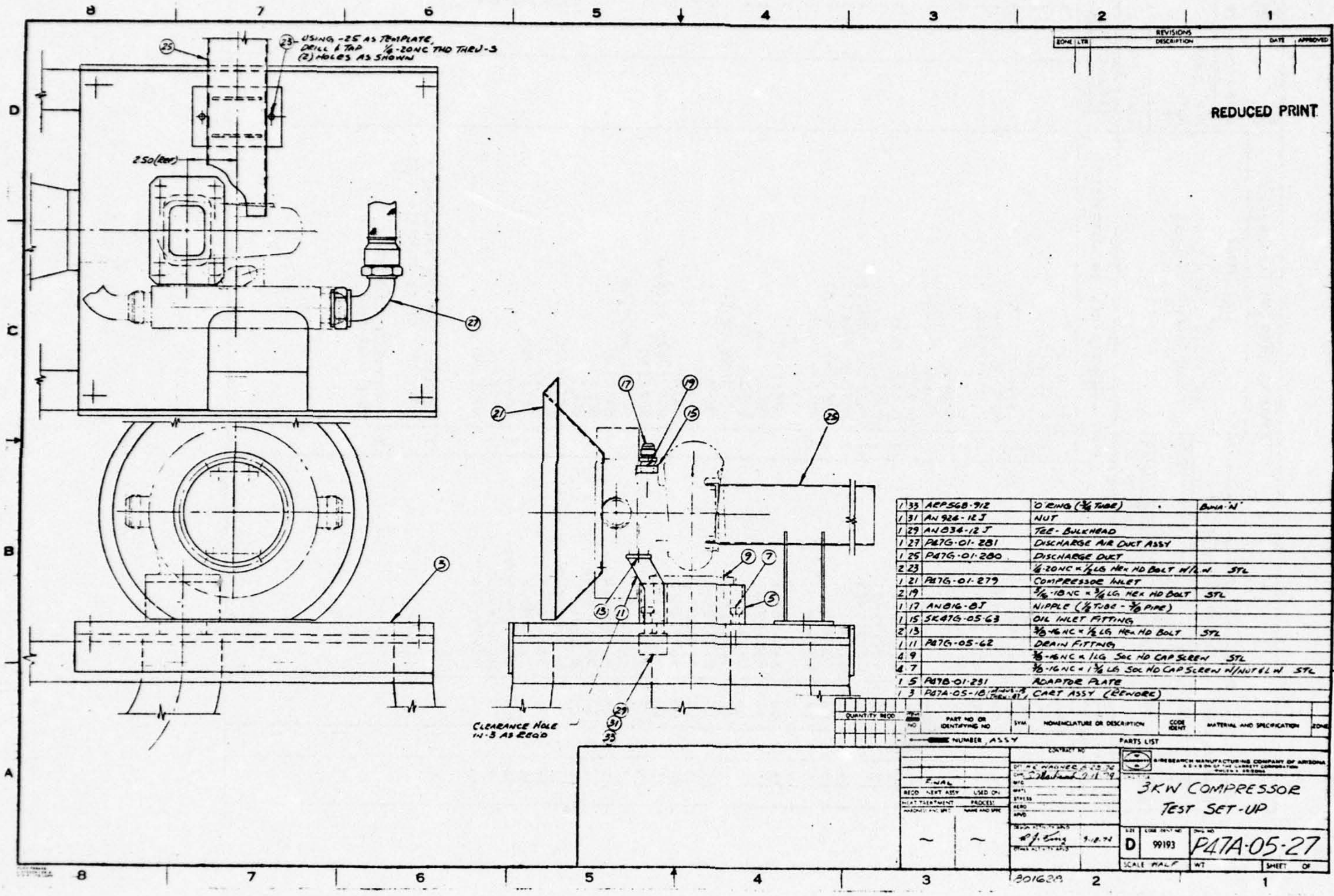
X/L	W/A	Z/L	R/L	MOM/L	DELTA*/L	M	(M)TT	CF TURB	PT MIX	CPM	AEFF/A	P STAT
0.00	.7636	.2298	0.0000	.404230E-03	.687789E-03	1.7015	1.4000	.345839E-02	48.6427	0.0000	.9526	32.4200
.02	.7416	.2322	0.0000	.475552E-03	.823548E-03	1.7320	1.4464	.317651E-02	48.5177	.0489	.9439	33.2770
.04	.7250	.2346	0.0000	.556004E-03	.977695E-03	1.7584	1.4868	.293324E-02	48.3662	.0855	.9342	33.9182
.06	.7097	.2370	0.0000	.636062E-03	.112724E-02	1.7723	1.5131	.277823E-02	48.2310	.1187	.9250	34.5017
.08	.6956	.2394	0.0000	.715950E-03	.127364E-02	1.7790	1.5309	.267250E-02	48.1089	.1492	.9161	35.0348
.10	.6809	.2420	0.0000	.801210E-03	.143253E-02	1.7880	1.5511	.256619E-02	47.9951	.1805	.9068	35.5846
.12	.6550	.2471	0.0000	.930416E-03	.171327E-02	1.8414	1.6230	.228351E-02	47.8793	.2349	.8908	36.5384
.14	.6330	.2521	0.0000	.105708E-02	.199379E-02	1.8861	1.6827	.207079E-02	47.7799	.2804	.8755	37.3357
.16	.6137	.2572	0.0000	.118170E-02	.227328E-02	1.9237	1.7327	.190631E-02	47.6934	.3193	.8607	38.0183
.18	.5967	.2622	0.0000	.130455E-02	.255126E-02	1.9557	1.7753	.177583E-02	47.6174	.3532	.8464	38.6126
.20	.5814	.2673	0.0000	.142577E-02	.282735E-02	1.9830	1.8119	.167004E-02	47.5498	.3831	.8327	39.1366
.22	.5676	.2723	0.0000	.154544E-02	.310124E-02	2.0067	1.8437	.158271E-02	47.4894	.4097	.8195	39.6032
.24	.5549	.2774	0.0000	.166359E-02	.337265E-02	2.0273	1.8715	.150953E-02	47.4351	.4337	.8067	40.0223
.26	.5434	.2824	0.0000	.178027E-02	.364134E-02	2.0454	1.8960	.144747E-02	47.3860	.4553	.7943	40.4013
.28	.5327	.2875	0.0000	.189548E-02	.390708E-02	2.0613	1.9177	.139429E-02	47.3415	.4749	.7824	40.7461
.30	.5228	.2926	0.0000	.200924E-02	.416969E-02	2.0753	1.9370	.134837E-02	47.3009	.4929	.7709	41.0614
.32	.5136	.2976	0.0000	.212156E-02	.442900E-02	2.0876	1.9542	.130845E-02	47.2639	.5095	.7598	41.3512
.34	.5050	.3027	0.0000	.223247E-02	.468488E-02	2.0985	1.9696	.127356E-02	47.2300	.5247	.7490	41.6186
.36	.4969	.3077	0.0000	.234198E-02	.493721E-02	2.1081	1.9833	.124294E-02	47.1990	.5388	.7386	41.8662
.38	.4893	.3128	0.0000	.245010E-02	.518590E-02	2.1166	1.9956	.121598E-02	47.1704	.5520	.7285	42.0965
.40	.4822	.3178	0.0000	.255687E-02	.543088E-02	2.1240	2.0066	.119217E-02	47.1442	.5642	.7187	42.3111
.42	.4754	.3229	0.0000	.266229E-02	.567208E-02	2.1305	2.0164	.117113E-02	47.1200	.5757	.7092	42.5118
.44	.4690	.3279	0.0000	.276640E-02	.590947E-02	2.1362	2.0251	.115249E-02	47.0977	.5864	.7000	42.7000
.46	.4629	.3330	0.0000	.286921E-02	.614302E-02	2.1410	2.0328	.113600E-02	47.0771	.5965	.6911	42.8768
.48	.4571	.3380	0.0000	.297075E-02	.637273E-02	2.1452	2.0397	.112139E-02	47.0592	.6060	.6824	43.0434
.50	.4516	.3431	0.0000	.307105E-02	.659858E-02	2.1486	2.0458	.110848E-02	47.0406	.6149	.6740	43.2006
.52	.4463	.3481	0.0000	.317012E-02	.682060E-02	2.1515	2.0511	.109709E-02	47.0244	.6234	.6659	43.3493
.54	.4413	.3532	0.0000	.326800E-02	.703980E-02	2.1539	2.0557	.108706E-02	47.0094	.6315	.6580	43.4901
.56	.4365	.3582	0.0000	.336470E-02	.725320E-02	2.1557	2.0597	.107826E-02	46.9955	.6391	.6503	43.6238
.58	.4318	.3633	0.0000	.346025E-02	.746384E-02	2.1570	2.0631	.107058E-02	46.9827	.6463	.6428	43.7509
.60	.4274	.3683	0.0000	.355468E-02	.767075E-02	2.1579	2.0660	.106392E-02	46.9709	.6532	.6355	43.8718
.62	.4231	.3734	0.0000	.364800E-02	.787398E-02	2.1584	2.0683	.105819E-02	46.9599	.6598	.6284	43.9871
.64	.4190	.3784	0.0000	.374025E-02	.807357E-02	2.1586	2.0703	.105331E-02	46.9498	.6661	.6215	44.0972
.66	.4151	.3835	0.0000	.383143E-02	.826957E-02	2.1583	2.0717	.104921E-02	46.9404	.6721	.6148	44.2024
.68	.4113	.3885	0.0000	.392159E-02	.846204E-02	2.1578	2.0728	.104583E-02	46.9318	.6778	.6082	44.3030
.70	.4076	.3936	0.0000	.401072E-02	.865104E-02	2.1570	2.0736	.104311E-02	46.9239	.6833	.6019	44.3994
.72	.4040	.3986	0.0000	.409887E-02	.883661E-02	2.1559	2.0739	.104100E-02	46.9166	.6886	.5956	44.4919
.74	.4006	.4037	0.0000	.418604E-02	.901882E-02	2.1545	2.0740	.103945E-02	46.9098	.6937	.5896	44.5807
.76	.3973	.4087	0.0000	.427227E-02	.919773E-02	2.1529	2.0738	.103843E-02	46.9036	.6985	.5837	44.6659
.78	.3940	.4138	0.0000	.435756E-02	.937340E-02	2.1511	2.0733	.103790E-02	46.8980	.7032	.5779	44.7479
.80	.3909	.4188	0.0000	.444193E-02	.954589E-02	2.1490	2.0725	.103781E-02	46.8928	.7077	.5723	44.8269
.82	.3879	.4239	0.0000	.452546E-02	.971543E-02	2.1468	2.0715	.103812E-02	46.8882	.7121	.5665	44.9031
.84	.3850	.4289	0.0000	.460794E-02	.988028E-02	2.1442	2.0701	.103928E-02	46.8828	.7161	.5613	44.9747
.86	.3821	.4340	0.0000	.468971E-02	.100437E-01	2.1417	2.0687	.104034E-02	46.8790	.7202	.5561	45.0456
.88	.3793	.4390	0.0000	.477069E-02	.102045E-01	2.1390	2.0671	.104169E-02	46.8757	.7241	.5509	45.1143
.90	.3766	.4441	0.0000	.485091E-02	.103628E-01	2.1363	2.0654	.104329E-02	46.8730	.7279	.5460	45.1811
.92	.3740	.4491	0.0000	.493044E-02	.105188E-01	2.1334	2.0636	.104510E-02	46.8709	.7316	.5411	45.2462
.94	.3714	.4542	0.0000	.500932E-02	.106727E-01	2.1306	2.0618	.104705E-02	46.8695	.7353	.5364	45.3098
.96	.3690	.4592	0.0000	.508759E-02	.108248E-01	2.1277	2.0599	.104912E-02	46.8698	.7388	.5318	45.3721
.98	.3665	.4643	0.0000	.516523E-02	.109749E-01	2.1248	2.0579	.105134E-02	45.8687	.7423	.5274	45.4329
1.00	.3642	.4693	0.0000	.524215E-02	.111225E-01	2.1217	2.0557	.105378E-02	46.8688	.7457	.5230	45.4920

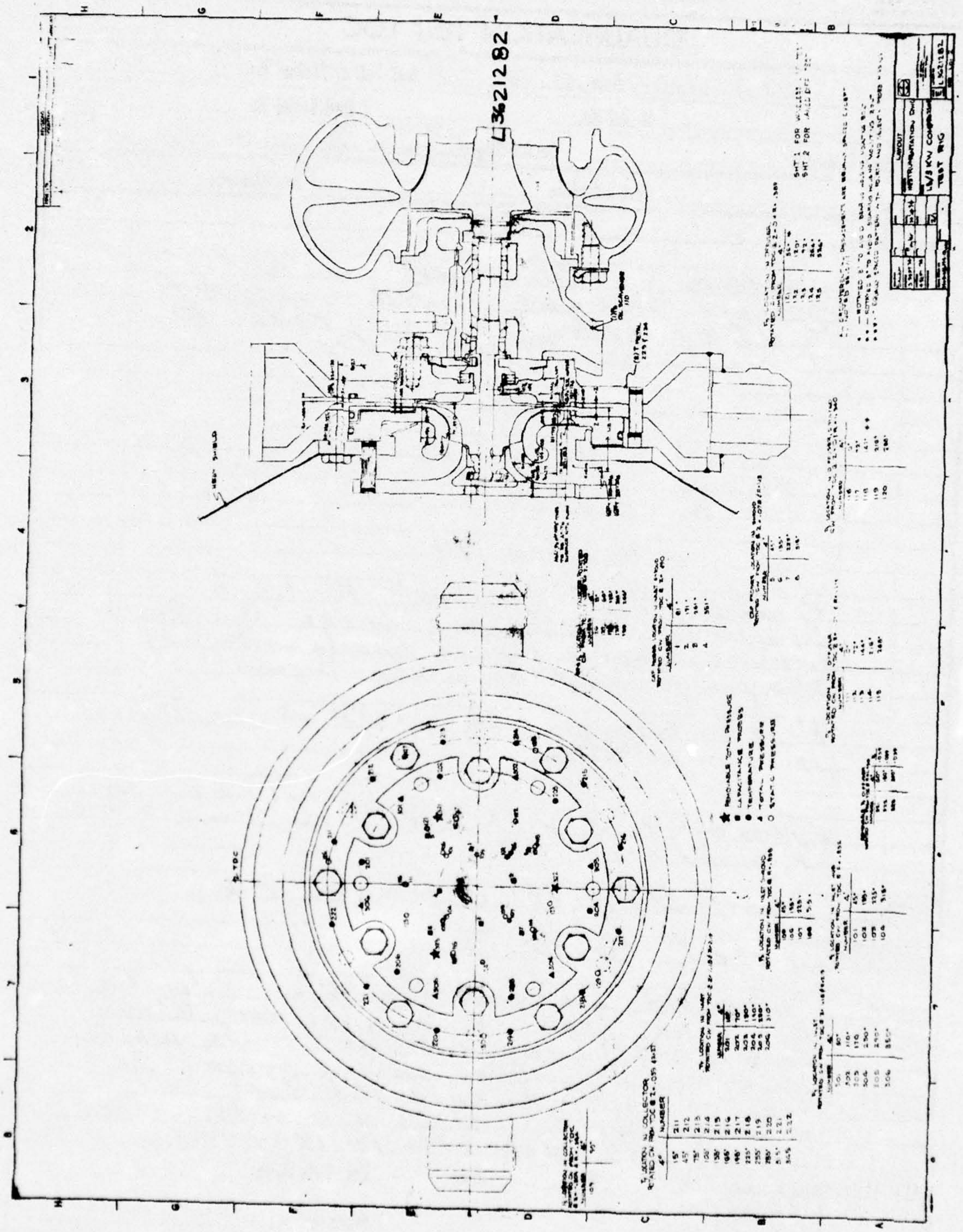

SHROUD COMPRESSOR
3604223
PART NUMBER
REMARKS
3604223-1 AS SHOWN
3604223-2 AS SHOWN & NOTED
VIEW D
NO SCALE
VIEW C
-2 CONFIGURATION ONLY
SHARP CORNER
TABLE I
TABLE II
SECTION H-H
SECTION G-G
SECTION L-L
NOTED


TEST RIG ASSEMBLY, COMPRESSOR
3604262
TIGHTEN TO 75-90 IN LBS TORQUE (4 PLACES)
LOCK BOLTS BY BENDING TABS (4 PLACES)
LOCK BOLTS IN PAIRS BY BENDING TABS (6 PLACES)
SEE SEPARATE PARTS LIST
FOR -2 ONLY
AS REQ'D TO OBTAIN DIM A
PART NUMBER
REMARKS
AS SHOWN
AS SHOWN EXCEPT AS NOTED
ASSEMBLE ON SHAFT WITH LOCTITE TO SECURE
PRIOR TO ASSY FILL RING GROOVE WITH DOW CORNING HIGH VACUUM SILICONE GREASE

	PARTS LIST	PL 3604262-1	REV LTR B (D)
CONTRACT NO. DAAK02-74-C-0167	LIST TITLE		DATE 07-01-75
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA, A DIVISION OF THE GARRETT CORPORATION, PHOENIX, ARIZONA	TEST RIG ASSEMBLY, COMPRESSOR-VANELESS		REV AUTH NO. ENGR
CODE IDENT NO. 99193 / APPROVAL J.B.L. / ORIGINAL ISSUE 06-27-74			SHEET 1 OF 1

FIND NO.	SHT NO.	DWG ZONE	PART NO. OR IDENTIFYING NO.	SYM	NOMENCLATURE OR DESCRIPTION	CODE IDENT	QTY REQD
1	1	B6	3604262-1		RIG ASSY		X
2	1	C4	400424	2	SEAL RING		1
3	1	D4	400544	2	LOCKNUT		1
4	1	C2	400568	2	RETAINER RING		4
5	1	F2	403818-9	2	RING-PISTON		1
6	1	E1	403818-34	2	RING-PISTON		1
7	1	C2	404221-1	2	BOLT		6
8	1	C4	406765-2	2	SPRING		1
9	1	D4	3604226-1		COLLAR THRUST		1
10	1	B2	406908-1	2	CLAMP		3
11	1	B2	406909	2	PLATE-LOCK		3
12	1	D1	407276-5	2	WHEEL ASSY		1
13	1	C1	407316-23	2	TURBINE HOUSING		1
14	1	C1	407565	2	SHROUD WHEEL		1
15	1	F2	407634	2	BEARING THRUST		1
16	1	G2	407684	2	PLATE-LOCK		2
17							
18	1	D4	3604188-1		IMPELLER		1
19	1	B4	3604222-1		COLLECTOR		1
20	1	D4	3604223-1		SHROUD		1
21	1	E4	3604225-1		HOUSING INLET		1
22	1	C4	3604228-1		SHIM		AR
23	1	C4	3604228-2		SHIM		AR
24	1	C4	3604228-3		SHIM		AR
25	1	E4	3604457-1		NUT SPEED PICK-UP		1
26	1	C2	3604252-1		BEARING		2
27	1	C2	3604253-1		CENTER HOUSING		1
28	1	C4	S8990-158		PACKING		1
29	1	G2	S9419-0002	2	BOLT		4
30	1	C5	AN4CH4A		BOLT		12
31	1	C5	MS20995C20		LOCKWIRE		AR
32	1	D4	3604494-1		PROBE		3
33	1	D4	3604495-1		RETAINER		3
34	1	D4	791-503-9001	1	WASHER		3
35	1	D4	MS35265-30		SCREW		6
36	1	D4	S8990-006		PACKING		3
				1	VENDOR ITEM SEE APPLICABLE SPEC OR SOURCE CONTROL DWG		
				2	AIRESARCH INDUSTRIAL DIVISION PART NO.		


REDUCED PRINT
USING -25 AS TEMPLATE, DRILL & TAP 1/4-20NC THD THRU-3 (2) HOLES AS SHOWN
2.50(REF)
CLEARANCE HOLE 1/4-3 AS REQD
1 33 ARP568-912 'O' RING (3/4 TUBE) BUNA 'N'
1 31 AN924-12J NUT
1 29 AN834-12J TEE - BULKHEAD
1 27 P47G-01-281 DISCHARGE AIR DUCT ASSY
1 25 P47G-01-280 DISCHARGE DUCT
2 23 1/4-20NC x 1/2 LG HEX HD BOLT W/LW STL
1 21 P47G-01-279 COMPRESSOR INLET
2 19 5/16-18NC x 3/4 LG HEX HD BOLT STL
1 17 AN816-8J NIPPLE (1/2 TUBE - 3/8 PIPE)
1 15 SK47G-05-63 OIL INLET FITTING
2 13 3/8-16NC x 1/2 LG HEX HD BOLT STL
1 11 P47G-05-62 DRAIN FITTING
4 9 3/8-16NC x 1 LG SOC HD CAP SCREW STL
4 7 3/8-16NC x 1 3/4 LG SOC HD CAP SCREW W/NUT & LW STL
1 5 P47B-01-231 ADAPTOR PLATE
1 3 P47A-05-18 CART ASSY (REWORK)
QUANTITY REQD
PART NO OR IDENTIFYING NO
NOMENCLATURE OR DESCRIPTION
CODE IDENT
MATERIAL AND SPECIFICATION
NUMBER ASSY
PARTS LIST
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
3KW COMPRESSOR TEST SET-UP
D 99193 P47A-05-27
SCALE HALF
P47A-05-27



FORM NO. P5330
150 BOOKS 1-68 AMPCO

AiResearch Manufacturing Company of Arizona — Page No. 26 of ____

QUALIFICATION TEST LOG

E.W.O. No. [illegible]-46154-01 [illegible] Date 10-21-74 Test Cell or Station No. C [illegible]

Assembly No. ____ Model No. ____ Unit Serial No. ____

Development Engineer ____ Technician Lawrence [illegible] Grp. Ldr. [illegible]

Test Type ____ Test Schedule ____ Modification ____

TIME START	TIME STOP	Event	O.C.
		installed 85-98 TURB ON NEW DESIGN TORQUE TUBE - ACCEL TO 43,000 RPM - MAX VIB. @ .39 mills @ 33,000 RPM.	
		10-25-74	
		Drained & Flushed cell oil system with 6081-1010 oil - installed new oil FILTER ELEMENTS [illegible]	
		18 Nov 74	
		Plumbed inlet + Exhaust Air lines. Could not find extension wires for Bently probes, Record said to check with day They may have to make them.	
		Note: Xducers not installed in Digital instrumentation	
		Cell Time 8hrs. Filled oil tank with 30 QT Tool time 2@ 8hrs Chk oil scor. OK.	
1500		start slo-roll - clearences OK.	
(20)	1610	accel to 100% SPD.	
1610		Connected Instrumentation from Rotor housing	
1800		Check out leak in DP System, Check each hose + line, could not determine where leak was at, After putting system back together did not have the leak as before Now the system close off, with 298 PSI Trapped will leak 2PSI in 18 minutes	

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

ORIGINAL

20 25 90% @ 9.8 #/sec

FORM NO. PS330
150 BOOKS 1-68 AMPCO

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QUALIFICATION TEST LOG

E.W.O. No. 3407 246154-01-0602	Date 11-21-74	Test Cell or Station No. C-114
Assembly No. —	Model No. 1.5/3 KYY	Unit Serial No. —
Development Engineer	Technician Dick Clark	Grp. Ldr. Macfarlane
Test Type Single stg	Test Schedule #1	Modification —

TIME START	TIME STOP	Event	O.C.
1230		Started to put shroud Assy together however was in doubt about Adjustment on the 3 Pins (item 23). Hold bolt have not been tighten.	
		Tech work & the Call time 8hrs	1.25
		installed 2 X 1.5 ORIF.	orif
		11-21-74	
		Hook up completed - Ready for Run	
1310		start up slowly to 90%	
		completed 90%	11-22-74
		Set up 100% - mux Problems.	
1530		12.5 waits AIR.	
		8.0 Hrs Run 3 techs @ 8.0 Hrs Each	
		11-22-74	
0800		start 100% - completed 100%	
	20	Down to install 2 X 1.25 ORIF	
	0910		
0951		start 80% - completed 80%	
	30	Start 60% - Ran 4 Points &	
		noticed noise, vib, lowered speed	
1110		to 40%, Down per Eng.	
		1 294	

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

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150 BOOKS 1-68 AMPCO

AiResearch Manufacturing Company of Arizona **Page No.** 28 **of** ____

QUALIFICATION TEST LOG

E.W.O. No. 3409-246/54-01-0602	**Date** 11-22-74	**Test Cell or Station No.** C-114
Assembly No. ~	**Model No.** 1.5/3 KVL	**Unit Serial No.** ~
Development Engineer Zanelli	**Technician** Dick + Park	**Grp. Ldr.** Macfarlane
Test Type Single stg	**Test Schedule** # 1	**Modification** —

TIME START	TIME STOP	Event	O.C.
		REMOVED TO DEV ASSY. BLEW AIR THRU RIG. TO REMOVE ALL FOREIGN MATERIAL. C.O. CAP. PROBE LOCATION # 3/4.	

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____
Total Manual Starts ____
Total Automatic Starts ____ Engineering ____

SPEED CPS		339	4204	4120	4680	4666	3729
CPS X 30 = RPM		10,170	126100	123600	140400	139980	111870
PERCENT SPEED N/√θ			90	90	100	100	80
V... ATICS		0	.03	.03	.03	.04	.04
POINT No			1	3	16	18	30
... PROBES MV #1		.085	.043		.057	.053	.041
#2		.056	.053		.050	.047	.050
#3		.049	.043		.037	.035	.045
#4		.039	.042		.046	.046	.046
#5		.064	.069		.067	.068	.075
#6		.057	.059		.060	.061	.067
#7		.058	.168		.066	.082	.077
#8		.067	.086		.071	.100	.093
OIL INLET PRESS PSIG		70	69.5	69	69	70	70
OIL SCAV PRESS "HgG.		-7.5	-8.5	-7	-5.4	-5.0	+2
IMPELLER BACKFACE "HgG		0	-5.0	+6.5	-4.0	14.0	16.5
OIL INLET TEMP DORIC 1	19	80	82	83	83	79	81
OIL SCAV TEMP	20	83	111	113	116	113	108
COMP INLET PRESS PSIG		-.0135	-.016	-.0138		-.0153	-.0145
COMP DISCH PRESS "Hg.		0	0	18.3	6.9	34.5	29.6
TURB INLET TEMP DORIC 2	19	277	542	500	498	499	494
	20	306	555	571	508	508	508
16927		0	19	20	25	27	14
... ΔP		0.45	15.1	15.7	17.6	18.4	14.6
			1.500				1.250

ALTITUDE EQUIPMENT DIVISION	
CALCULATED	
RECORDED	
DRAWN	
CHECKED	
APPROVED	

AiResearch Manufacturing Company of Arizona

SPEED	CPS	337	775	[illegible]	1280	1723	[illegible]	[illegible]	[illegible]	[illegible]
	X 30 = RPM	10100	23,200	29998	38,400	51,700	70900	95,400	120,000	139,200
VIB	MILLS	0	0	0	0	[illegible]	0	.036	0.3	[illegible]
CAP PROBES	MV 1	.031	[illegible]	.031	.031	[illegible]	[illegible]	[illegible]	.041	[illegible]
	2	.053	.033	[illegible]	—	.036	.033	.052	.052	[illegible]
	3	[illegible]	.031	.063	—	—	.031	.049	.040	.039
	4	.041	.030	.040	.039	—	.041	[illegible]	.035	.041
	5	.040	[illegible]	.043	.040	.041	.041	[illegible]	.041	.043
	6	.030 [illegible]	.036	.038	.036	.037	.039	[illegible]	.035	.041
	7	.010 .037	.036	.037	.031	.036	.039	.042	.040	.043
	8	.044	.043	.045	.042	.047	.044	.050	.050	.050
OIL IN PRESS	PSIG	70	70	70	70	70	70	67	67	69
OIL OUT PRESS	PSIG "HG	-3	-3	-3	-3	-3	-3	-15	-15	-15
IMP. BACKFACE		0	0	1	1	1	1	1	2	3
OIL IN TEMP	°F	77	77	77	77	80	80	80	80	81
OIL OUT TEMP	°F	55	80	74	92	97	98	100	106	111
TIT	°F	225/209	367/348	[illegible]/373	373/374	413/438	424/[illegible]	[illegible]	[illegible]	[illegible]
CIT	°F									
CDP	IN Hg PSI	0	0	0	1	2	3	6	8.5	10
[illegible]	H_2O	1.7	7.5	15.5	25	60	60	60		

[illegible]

ALTITUDE EQUIPMENT DIVISION		
CALCULATED		
RECORDED		
DRAWN		
CHECKED		
APPROVED		

1.5/3 KW MERDC
MECH. CHECK
PER DT 6020

AiResearch Manufacturing Company of Arizona

FORM NO. PS330
150 BOOKS 1-68 AMPCO

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QUALIFICATION TEST LOG

E.W.O. No. | Date 24 JUNE, 1975 | Test Cell or Station No. C-114

Assembly No. | Model No. | Unit Serial No.

Development Engineer | Technician NORWOOD | Grp. Ldr. MACFARLANE

Test Type | Test Schedule | Modification

TIME START	TIME STOP	Event	O.C.
		FLUSHED OIL SYSTEM. INSTALLED ALL NEW FILTERS & REFILLED OIL TANK. NO OIL IN SYSTEM BECAUSE OF NO TORQUE TUBE.	
		OIL SYSTEM REFILLED.	
		4 AUG. 75	
		INSTALLED TORQUE TUBE. RAN TURB TO 40,000 RPM. MAX. VIB. 0.32 MILS AT 21,850 RPM.	
		Sept 12-75	
		DRAINED all mobil Jet oil From Tank. Flushed all inlet & Disch oil lines after Removing all oil lines From Turb with solvent installed inlet & Disch oil Filter Elements - no oil avail. as yet For Flush & Refill of 30 wt auto oil.	
		Sept 15-75	
		Flushed oil system with 5 Gals 30 wt oil - System now needs 5 Gals 30 wt oil. General Hook up in progress. Need Vib. Hook up By Lee Schmitt.	
		Vib. Hook up now OK. Oil system Has Been Serviced with 5 Gals 30 wt oil. Oil scav. ck. OK. Per Eng.	
1340 (10) 1350		Accel to approx. 25% speed for Cap probe clearence ck.	
		1.5 G's Vib.	
1135		Ran s/o Roll - 20% speed. 40,000 RPM 2 G's Vib, 60,000 RPM 4.0 G's	

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______

Total Manual Starts ______

Total Automatic Starts ______ Engineering ______

8.5

FORM NO. PS330
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QUALIFICATION TEST LOG

E.W.O. No. 3409-346/51-00034 | Date Sept 16, 75 | Test Cell or Station No. C-114

Assembly No. ~ | Model No. 1.5/3 KW | Unit Serial No. ~

Development Engineer R.F. Howe | Technician Lawrence | Grp. Ldr. Macfarlane

Test Type Single A6. | Test Schedule #2 & 3 | Modification —

TIME START	TIME STOP	Event	O.C.
1435		@ 80,000 RPM 8.5 G's	
		SPEED @ 90% VIB. IS EXCESSIV,	
1500		@ 15 G's.	
		DOWN PER ENG. Hold FOR	
		DECISION.	
NOTE		TO READ RPM ON ANNIDEX	
		MULTIPLY X 30	
		Sept 17, 75	
		installed Real time annilizer.	
0820		start S/o-Roll accel to 40,000 RPM	
		VIB. @ 2 G's, accel to 60,000 RPM	
		3.6 G's VIB. accel to 80,000 RPM	
		7.2 G's, accel to approx 85,000	
30		RPM VIB. @ 10.0 G's, NOTE OVER	
		15 G's @ 90,000 to 95,000 RPM.	
0850		DOWN PER ENG.	
		ck.o VIB. Equip.	
0945		accel to 2.0 G's @ 40,000 RPM	
		@ 60,000 RPM VIB. @ 3.5 G's	
		@ 80,000 RPM VIB @ 7.5 G's	
		@ 82,220 RPM VIB. @ 14.5 G's - PcD 2.8	
1005		DOWN PER ENG.	
		Put VIB. FILTER in PER ENG.	
Note 1020		@ 100,000 RPM @ 1 G VIB. Filtered	
		@ 120,000 RPM @ 5.0 G's VIB. Filtered	
		@ 140,000 RPM @ 5.5 G VIB. Filtered	
		50 G's without Filter	
		@ 150,000 VIB @ 14 G's Filtered.	
		unit OK. PER ENG - DOWN FOR	
		Look.	
		Sept 18-75	
0850		accel to 60% FOR Digital	
0900		scan ck.	

SUMMARY: Total Running Time ______ hrs. ______ min. Ref. Data Page ______

Total Manual Starts ______

Total Automatic Starts ______ Engineering ______

ORIGINAL

.16 .13 .10 .07 .05
110 100 90 80 60

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QUALIFICATION TEST LOG

E.W.O. No. 3409-JH6154-02-0301 Date Sept 18, 75 Test Cell or Station No. C-114

Assembly No. 2 Model No. 1.5/3 KW Unit Serial No.

Development Engineer R.E. HONN Technician Laurence Grp. Ldr.

Test Type Single Stg Test Schedule # 2 & 3 Modification

TIME START	TIME STOP	Event	O.C.
1010		start 100% - completed 100%	
	25	.008 clearence.	
1125		DOWN TO RESHIM COMP.	
		CLEARENCE NOW @ .0045	
815		ACCEL TO 140,000 RPM TO MAKE	
(10)		CLEARENCE CK. O.K. @ .005-.006	
	825		
		RPM 0 - OFFSET.	
0945		start 100% - completed 100%	
(1125)		start 90% - completed 90%	
1200		start 80% - completed 80%	
1245		start 60% completed 60%	
(25)		START 110% completed 110%	
1400		DOWN TO RESHIM.	
		CLEARENCE .0025	
		22.0 mins AIR	
		8.0 HRS FOR	
		start TEST #3	
1350		ACCEL TO 100%	
1600		DOWN TO RESHIM.	
		Sept 22, 75	
		RESHIMED COMPRESSOR	
		CLEARENCE @ .005	
925		ACCEL TO 80,000 RPM - LOST	
0930		SPEED COUNT ON ANHIDEX	
		PROBLEM WAS RECORDING CART TACK.	
		REPLACED tack NOW O.K.	
1145		ACCEL TO 80,000 RPM - CLEARENCE @ .005	
		ACCEL TO 120,000 RPM - VIB. O.K.	
		CLEARENCE @ .005 - ACCEL TO 140,000 RPM	
1155		CLEARENCE @ .004 - DOWN	

SUMMARY: Total Running Time ____ hrs. ____ min. Ref. Data Page ____

Total Manual Starts ____

Total Automatic Starts ____ Engineering ____

63 PCD .13#/SEC 100%

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150 BOOKS 1-68 AMPCO

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QUALIFICATION TEST LOG

E.W.O. No. 3509-246154-02-030 Date Sept 22, 75 Test Cell or Station No. C-114
Assembly No. ~ Model No. 1.5/3 KW Unit Serial No.
Development Engineer Monty Technician Dick & Park Grp. Ldr. Mac
Test Type Single Stg Test Schedule #2 & 3 Modification ~

TIME START	TIME STOP	Event	O.C.
		RESHIMMED COMPRESSOR TO .004	
1255		ACCEL TO 80,000 RPM — CLEARENCE @ .0023	
1300		DOWN TO .001 @ 120,000 RPM DOWN PER ENG. OK TO RUN PER ENG.	
1340		ACCEL TO 120,000 RPM - DOWN TO RE-SHIM.	
1400			
1430		ACCEL TO 80,000 RPM — CLEARENCE @ .003. ACCEL TO 100,000 RPM — CLEARENCE @ .0025 — ACCEL TO 120,000 RPM — CLEARENCE @ .00175 @ 122,000 RPM CLEARENCE	
1445		@ .001 DOWN TO RESHIM.	
1505		ACCEL TO 80,000 RPM — CLEARENCE	
1515		@ .005 ACCEL — CLEARENCES EXCESSIVE. RESHIMMED COMP. Sept 23, 75	
0835		ACCEL "WITH HEAT" TO 100% SPEED — CLEARENCES @ .0023	
0853		DOWN TO SAFETY LIMIT.	
0925		ACCEL TO 100,000 RPM — MUX BLEW — DOWN TO RE-BOOT.	
1005	35	ACCEL TO 100% @ 141,630 RPM FOR DATA. RAN 3 POINTS — NOTED	
1040		GRIE. P_1 PROBLEM — DOWN TO CK. BLEW OUT DP & P_1 LINES.	
1125	45	ACCEL TO 100% — COMPLETED 100%	
1210		DOWN FOR LUNCH	
1300		START 90% — COMPLETED 90% START 80% COMPLETED 80% START 60% — COMPLETED 60%	

SUMMARY: Total Running Time ___ hrs. ___ min. Ref. Data Page ___
Total Manual Starts ___
Total Automatic Starts ___ Engineering ___

.16#/SEC
1109

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150 BOOKS 1-68 AMPCO

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QUALIFICATION TEST LOG

E.W.O. No. 3409-246154-02-0301 **Date** Sept 23, 75 **Test Cell or Station No.** C-114

Assembly No. — **Model No.** 1.5/2 KW **Unit Serial No.** —

Development Engineer Marty **Technician** Bob & Dick **Grp. Ldr.** Mac

Test Type 1st stg **Test Schedule** #2 & 3 **Modification** —

TIME START	TIME STOP	Event	O.C.
		start 95% - completed 95%	
1400		start ~~105~~ % 110% - completed 110%	
		Start 105% - completed	
1600		25 mins air. (DOWN)	
		8.0 HRS EHC	

SUMMARY: **Total Running Time** ____ **hrs.** ____ **min.** **Ref. Data Page** ____
Total Manual Starts ____
Total Automatic Starts ____ **Engineering** ____

ORIGINAL

Data Point No.	0	1	2	3	4	5	6	7	8	
Time		10 06 01	10 14 01	10 19 01	10:25:31	10 30 31	10 35 31	10 39 01	10 47 01	
% Speed		100	100	100	100	100	100	100	100	
Speed - ~~RPM~~ CPS		4711	4705	4712	4715	4713	4709	4710	4725	
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel. G's		7.5	8.8	8.9	9.2	9.3	9.0	9.0	9.4	
Neg InHg Ref	10.0	10.0			10.0					
Neg InH_2O Ref	50.0	50.0			50.0					
Check Cap Probes	.033/.047	.038 .050	O.K.	O.K.	.038 .049	OK	OK	O.K.	.038 .049	
	—/.043	— .047			— .047				— .048	
	.058/.051	.084 .073			.091 .073				.086 .075	
	.050/.058	.073 .091			.073 .091				.076 .093	
Tank Amb										
~~Bell~~ Orif. ΔP		36.0	36.3	36.0	34.6	30.3	28.3	25.2	23.2	
~~Bell~~ Surge ΔP									22.5	
Comp. Dischg. "Hg.G.		27.5	36.3	50.2	58.2	63.6	65.5	66.5	66.9	
Inlet Temp °F CRT		68.8	68.3	69.5	69.7	68.8	68.8	68.6	71.6	
$W_a\sqrt{\theta}/\delta$ CRT		.140	.140	.139	.136	.128	.121	.116	.112	
P.R. CRT		1.02	2.16	2.88	3.19	3.37	3.44	3.48	3.51	
Eff. CRT		.009	.444	.641	.703	.732	.736	.735	.733	
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT. 1975 BAROMETER 14.1166 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 2

TEST TITLE STAGE PERFORM. W/ VANED DIFF. NOMINAL CLEARANCE PAGE 1

Data Point No.	9	10	11	12	13	14	15			
Time	11 03 01	11 08 01	11 11 31	11 14.31	11 18 01	11 22 31	11 28 31			
% Speed	90	90	90	90	90	90	90			
Speed - ~~RPM~~ CPS	4222	4225	4228	4225	4225	4229	4222			
Comp Vib Mils										
Turb Vib ~~Mils~~ ACCEL G's	4.5	4.5	4.5	4.7	4.9	5.0	4.5			
Neg InHg Ref	10.0				10.0					
Neg InH_2O Ref	50.0				50.0					
Check Cap Probes	.037 .048	O.K.	OK.	O.K.	.037 .049	O.K.	OK			
	— .047				— .047					
	.079 .067				.081 .071					
	.068 .083				.071 .087					
Tank Amb										
~~Bell~~ ORIF ΔP	25.2	25.2	24.3	21.4	16.4	15.5	18.3			
Bell Surge ΔP						15.8				
COMP. DISCHG. "HG.G.	23.8	34.5	40.7	45.7	49.0	49.4	48.4			
Inlet Temp °F CRT	63.6	65.6	66.1	65.0	65.1	66.4	64.4			
$W_a\sqrt{\theta}/\delta$ CRT	.119	.119	.117	.110	.097	.091	.102			
P.R. CRT	1.94	2.33	2.55	2.74	2.87	2.88	2.83			
Eff. CRT	.473	.620	.689	.735	.749	.741	.747			
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT. 1975 BAROMETER ______ TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 2

TEST TITLE STAGE PERFORM W/VANED DIFF. NOMINAL CLEARANCE PAGE 2

Data Point No.	16	17	18	19	20	21	22			
Time	11 34 01	11 37 31	11 41 31	11 45 31	11 48 01	11 57 31	11 58 31			
% Speed	80	80	80	80	80	80	80			
Speed - CPS	3754	3754	3753	3751	3755	3759	3760			
Comp Vib Mils										
Turb Vib Mils Gs	1.8	1.9	1.9	1.9	1.9	1.9	1.9			
Neg InHg Ref	10.0				10.0					
Neg InH_2O Ref	50.0				50.0					
Check Cap Probes	.036 .049	OK	OK	O.K.	.037 .049	OK	OK			
	— .045				— .046					
	.078 .064				.080 .065					
	.064 .078				.065 .029					
Tank Amb										
~~Bell~~ ORIF ΔP	17.3	17.2	16.9	14.4	11.8	9.0	8.7			
Bell Surge ΔP							8.5			
COMP. DISCHG. "Hg.G.	14.2	20.8	26.7	32.1	34.9	35.6	34.8			
Inlet Temp °F CRT	65.2	64.8	64.4	64.2	65.2	65.8	66.7			
$W_a\sqrt{\theta}/\delta$ CRT	.101	.101	.100	.093	.083	.072	.072			
P.R. CRT	1.18	1.82	2.04	2.26	2.35	2.38	2.38			
Eff. CRT	.137	.539	.650	.738	.757	.747	.744			
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT. 1975 BAROMETER 14.11 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 2

TEST TITLE STAGE PERFOR. W/VANED DIFF. NOMINAL CLEARANCE PAGE 3

Data Point No.	23	24	25	26	27	28	29			
Time	125326	125656	130026	130356	130756	131156	131556			
% Speed	60	60	60	60	60	60	60			
Speed - CPS	2880	2880	2881	2882	2882	2887	2886			
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel G's	0.4	0.3	0.3	0.3	0.3	0.3	0.3			
Neg InHg Ref	10.0						10.0			
Neg InH_2O Ref	50.0						50.0			
Check Cap Probes	.035 .049	OK	OK	OK	OK.	OK.	OK.			
	– .045									
	.071 .059									
	.057 .069									
Tank Amb										
~~Bell~~ ΔP ORIF "H_2O	8.0	8.2	7.5	6.5	4.5	3.1	5.3			
Bell Surge ΔP						3.0				
Comp. Dischg. "Hg.G.	4.6	6.8	11.5	13.8	15.9	16.5	15.6			
Inlet Temp °F CRT	88.9	88.9	89.6	90.0	90.1	91.9	91.3			
$W_a\sqrt{\theta}/\delta$ CRT	.070	.071	.067	.062	.050	.041	.055			
P.R. CRT	1.13	1.28	1.47	1.57	1.65	1.68	1.63			
Eff. CRT	.197	.404	.626	.720	.778	.775	.763			
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT, 1975 BAROMETER 14.0976 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 2

TEST TITLE STAGE PERFOR. W/VANED DIFF. NOMINAL CLEARANCE PAGE 4

Data Point No.	30	30	31	32	33	34	35			
Time		132926	133356	133756	134256	135026	135456			
% Speed	110	110	110	110	110	110	110			
Speed - ~~RPM~~ CPS	5191	5191	5186	5181	5180	5188	5193			
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel G's	7.5	7.5	8.8	8.7	8.8	10.0	9.0			
Neg InHg Ref	10.0	10.0				10.0				
Neg InH_2O Ref	50.0	50.0				50.0				
Check Cap Probes	.0	.038 .052	OK.	O.K.		OK.	OK			
		— .046								
		.092 .074			.106 .078	.109 .080				
		.076 .095			.079 .099	.081 .101				
Tank Amb										
~~Bell~~ Δ P Orif. "H_2O		49.1	49.5	48.0	43.0	38.4	45.8			
Bell Surge Δ P	.038 .052					37.7				
Comp.	— .046	39.0	63.1	74.0	82.4	85.8	80.2			
	.092 .074									
Inlet Temp °F CRT	.076 .095	71.2	69.4	68.8	68.2	70.7	70.9			
$W_a\sqrt{\theta}/\delta$ CRT		1.57	.157	.155	.146	.138	.151			
P.R. CRT		2.32	3.41	3.80	4.09	4.21	3.98			
Eff. CRT		.417	.624	.685	.712	.718	.702			
Orifice Size 2D	1.250	1.250								
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT. 1975 BAROMETER 14.0896 TEST CREW LAWRENCE, NORWOOD CELL C-113

TEST NO. 2

TEST TITLE STAGE PERFORM W/ VANED DIFF. PAGE 5

Data Point No.	0	1	2	3	4	5	6	7	8	9
Time	101036	103306	103706	104506	104936	105336	105706	110006	110406	112045
% Speed		100	100	100	100	100	100	100	100	100
Speed - ~~RPM~~ CPS	S/R	4725	4719	4708	4702	4704	4718	4717	4713	4718
Comp Vib Mils										
Turb Vib ~~Mils~~ Accl. G's	0	10	10	9.2	9.2	9.4	9.6	9.8	10.0	9.8
Neg InHg Ref	10.0	10.0								
Neg InH_2O Ref	50.0	50.02								
Check Cap Probes	.033/.050	OK.	O.K.	OK.	.037/.045	OK.	O.K.	.037/.045	OK.	.037/.045
	.047/.037				.046/.047			.047/.047		.047/.047
	.052/.036				.057/.045			.063/.046		.062/.046
	.034/—				.044/—			.045/—		.046/—
Tank Amb	—									
~~Bell~~ ORIF. ΔP	0.0	34.3	34.4	34.4	33.7	30.9	29.1	25.9	23.2	22.9
~~Bell~~ Surge ΔP										21.8
Comp. Dischg. "HG				44.1	53.8	59.4	60.8	62.7	64.1	63.7
Inlet Temp °F CRT		72.2	70.5	67.1	66.8	68.3	69.6	70.3	69.3	69.9
$W_a\sqrt{\theta}/\delta$ CRT		.1x35	.1x38	.1x35	.1x34	.1x28	.1x24	.117	.111	.109
P.R. CRT		2.23	1.03	2.62	2.99	3.19	3.25	3.34	3.38	3.39
Eff. CRT		.466	.016	.575	.665	.704	.711	.719	.717	.716
Orifice Size 2.	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 18 SEPT. 1975 BAROMETER 14.0876 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3 OPEN

TEST TITLE STAGE PERFORM. W/VANED DIFF. OPEN CLEARANCE PAGE 1

SLOW ROLL
AFTER
SHIMMING

.031 .008
.055 .0085
.055 .007
.038 .0085

.068 .006
.053 .0075
.049 .008
.057 .008

Data Point No.	~~10~~	~~10~~	10	11	12	13				
Time			101915	102415	102815					
% Speed	100	100	100	100	100	100				
Speed - ~~RPM~~ CPS		4730	4719	4710	4711					
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel G's		13	9.8	9.5	9.7					
Neg InHg Ref	10.0		10.0							
Neg InH_2O Ref	50.0		50.0							
Check Cap Probes	– .052	– .051	.038 .054	O.K.	OK.					
	.053 .048	.052 .047	.047 .048							
	.105 .081	.097 .080	.141 .113							
	.084 .104	.084 .104	.119 .155							
Tank Amb										
~~Bell~~ ΔP Orif. "H_2O		26.4	31.8	31.8	28.4					
Bell Surge ΔP										
Comp. Dischg. "Hg.G.		65.6	25.9	53.3	66.6					
Inlet Temp °F CRT		73.3	70.4	68.8	69.0					
$W_a\sqrt{\theta}/\delta$ CRT		.117	.132	.131	.124					
P.R. CRT		3.49	2.05	3.03	3.49					
Eff. CRT		.734	.420	.668	.744					
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 19 SEPT. 1975 BAROMETER 14.1906 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE STAGE PERFORM W/ VANED DIFF. MINIMUM CLEARANCE PAGE 2

Data Point No.	~~13~~ 13	14	15	16	17	18	19			
Time	11:37:04	11:41:04	11:45:04	11:48:34	11:52:34	11:55:34	12:02:04			
% Speed	100	100	100	100	100	100	100			
Speed - ~~RPM~~ CPS	4709	4704	4705	4704	4703	4706	4710			
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel G's	9.5	9.0	9.0	9.0	9.1	9.1	7.7			
Neg InHg Ref	10.0						10.0			
Neg InH_2O Ref	50.0						50.0			
Check Cap Probes	.037 .053	O.K.	O.K.	.038 .053	OK	O.K.				
	.048 .048			.047 .048						
	.147 .113			.138 .112			.140 .113			
	.119 .152			.118 .152			.116 .150			
Tank Amb										
~~Bell~~ ΔP Orif. "H_2O	39.2	39.0	36.0	31.8	30.0	27.0	24.8			
Bell Surge ΔP							24.0			
Comp. Dischg. "Hg.G.	32.2	55.8	64.3	68.0	69.0	70.2	71.5			
Inlet Temp °F CRT	67.5	67.4	67.7	67.3	67.0	67.8	67.7			
$W_a\sqrt{\theta}/\delta$ CRT	.146	.146	.139	.130	.127	.120	.115			
P.R. CRT	2.35	3.07	3.36	3.48	3.52	3.58	3.61			
Eff. CRT	.497	.678	.729	.744	.746	.749	.740			
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 23 SEPT. 1975 BAROMETER 14.1746 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE STAGE PERFORM W/VANED DIFFUS. MINIMUM CLEARANCE. PAGE 3

Data Point No.	20	21	22	23	24	25				
Time	13:11:06	13:14:36	13:18:06	13:22:36	13:26:17	13:36:17				
% Speed	90	90	90	90	90	90				
Speed - CPS	4232	4230	4232	4233	4232	4224				
Comp Vib Mils										
Turb Vib Accel G's	4.0	4.4	4.6	4.8	4.8	4.7				
Neg InHg Ref	10.0				10.0					
Neg InH_2O Ref	50.0				50.0					
Check Cap Probes		.037 .053			.037 .052					
		.048 .048			.047 .048					
	.127 .103				.126 .102					
	.105 .135				.105 .133					
Tank Amb										
Orif. ΔP	26.0	24.3	20.2	17.2	15.6	26.2				
Bell Surge ΔP					14.8					
Comp Dischg. "Hg.G.	24.4	46.6	51.3	52.8	53.2	42.8				
Inlet Temp °F CRT	67.1	66.8	67.0	67.1	67.7	65.3				
$W_a\sqrt{\theta}/\delta$ CRT	.122	.118	.107	.098	.093	.121				
P.R. CRT	1.96	2.72	2.88	2.94	2.95	2.57				
Eff. CRT	.478	.732	.759	.762	.755	.686				
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 23 SEPT. 1975 BAROMETER 14.1566 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE STAGE PERFORM W/ VANED DIFFUSER MINIMUM CLEARANCE PAGE 4

Data Point No.	26	27	28	29	30	31	32	33	34	35	36
Time	13:48.41	13:54:16	13:56:46	14:03:16	14:07:46	14:14:16	14:17:46	14:22:16	14:25:16	14:29:46	14:37.46
% Speed	80	80	80	80	80	60	60	60	60	60	60
Speed - ~~RPM~~ CPS	3748	3749	3749	3755	3757	2813	2807	2806	2808	2810	2825
Comp Vib Mils											
Turb Vib ~~Mils~~ Accel G's	1.5	1.6	1.5	1.5	1.5	.4	.4	.4	.4	.3	.3
Neg InHg Ref	10.0										10.0
Neg InH_2O Ref	50.0										50.0
Check Cap Probes	.035 .053	OK	OK	OK.	.035 .053	.033 .053	OK	O.K.	OK.	O.K.	O.K.
	.048 .046				.048 .046	.049 .044					
	.115 .093				.115 .093	.103 .081					
	.093 .119				.094 .120	.078 .099					
Tank Amb											
~~Bell~~ ΔP Orif. "H_2O	18.1	16.8	13.7	11.4	9.8	9.1	8.0	7.1	5.7	4.5	3.13
Bell Surge ΔP					9.2						2.9
Comp. Dischg. "Hg.G.	15.1	32.0	36.8	38.3	38.2	5.5	13.0	15.0	17.0	18.0	18.4
Inlet Temp °F CRT	63.1	63.0	63.6	65.0	65.6	61.9	61.9	61.3	62.3	62.7	65.0
$W_a\sqrt{\theta}/\delta$ CRT	.103	.099	.090	.081	.075	.073	.070	.066	.059	.052	.042
P.R. CRT	.120	2.21	2.36	2.42	2.43	1.16	1.50	1.58	1.65	1.69	1.71
Eff. CRT	.156	.722	.765	.769	.762	.214	.635	.713	.766	.781	.764
Orifice Size 2D	1.250										
Bell No. 1 Dia											
Bell No. 2 Dia											

DATE 23 SEPT. 1975 BAROMETER 14.1456 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE ______ PAGE 5

Data Point No.	37	38	39	40	41	42	43	44	45	46
Time	14:45:46	14:50:16	14:54:46	14:58:46	15:03:46	15:13:15	15:20:14	15:24:44	15:28:14	15:32:44
% Speed	95	95	95	95	95	110	110	110	110	110
Speed - RPM	4439	4452	4456	4447	4454	5148	5188	5164	5160	5164
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel	8.6	10.9	11.0	11.1	11.5	8.8	4.5	3.5	3.2	2.7
Neg InHg Ref	10.0		#		10.0			10.0		
Neg InH_2O Ref	50.0				50.0			50.0		
Check Cap Probes	.038 .053	O.K.			.038 .052	.038 .055		.039 .054		.037 .054
	.047 .048				.046 .048	.048 .048		.047 .048		.048 .048
	.133 .113				.130 .108	.150 .122		.139 —		.137 —
	.116 .153				.110 .142	.128 .174	.124	.120 .162		.120 .159
Tank Amb										
~~Bell~~ Δ P ORIF "H_2O	30.3	30.0	27.0	23.2	19.2	49.9	48.8	46.6	44.3	51.0
Bell Surge Δ P					18.5					
Comp Dischg. "Hg. G.	25.4	52.7	58.0	60.1	61.8	39.4	79.5	85.6	88.3	69.1
Inlet Temp °F CRT	60.9	64.2	64.3	62.5	64.0	62.1	66.8	66.0	65.4	65.4
$W_a \sqrt{\theta}/\delta$ CRT	.134	.130	.122	.113	.103	.161	.158	.155	.150	.161
P.R. CRT	1.01	2.95	3.13	3.21	3.26	2.36	3.92	4.13	4.22	3.52
Eff. CRT	.008	.718	.746	.754	.746	.425	.694	.716	.722	.639
Orifice Size 2D	1.25									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 23 SEPT. 1975 BAROMETER 14.1366 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE

PAGE 6

Data Point No.	47	48	49	50	51					
Time	15:55:56	16:06:10	16:09:40	16:13:40	16:17:40					
% Speed	105	105	105	105	105					
Speed - ~~RPM~~ CPS	4928	4921	4918	4918	4929					
Comp Vib Mils										
Turb Vib ~~Mils~~ Accel. G's	12.9	13.0	13.0	13.5	13.0					
Neg InHg Ref	10.0				10.0					
Neg InH_2O Ref	50.0				50.0					
Check Cap Probes	.037 [illegible]	O.K.	O.K.	O.K.	.038 .052					
	.049 .049				.047 .049					
	.139 —				.140 —					
	.119 .158				.122 .157					
Tank Amb										
~~Bell~~ Δ P Orif. "H_2O	45.6	45.1	42.0	37.5	33.9					
Bell Surge Δ P										
Comp. Dischg. "H_2O	32.6	58.0	72.2	78.0	79.5					
Inlet Temp °F CRT	64.8	63.6	63.0	63.0	64.7					
$W_a\sqrt{\theta}/\delta$ CRT	.154	.154	.149	.140	.183					
P.R. CRT	2.33	3.13	3.67	3.84	3.92					
Eff. CRT	.458	.627	.715	.731	.736					
Orifice Size 2D	1.250									
Bell No. 1 Dia										
Bell No. 2 Dia										

DATE 23 SEPT. 1975 BAROMETER 14.1266 TEST CREW LAWRENCE, NORWOOD CELL C-114

TEST NO. 3

TEST TITLE

PAGE ~~6~~ 7

PCT SPD	SCAN	CORR SPEED	ORIFICE W CORR.	B/M W CORR.	SURGE FLOW	STAGE PT2/PT1	IMPLLR PT2/PT1	IMPLLR PS2/PT1	IMPLLR PHI	DIFF LOSS	DELTA T/T	STG EFF	IMP EFF	AXIAL CLEAR	2ND STG W CORR.	2ND STG CORR SPD
100.0	1	140058.	.152	0.000		3.081	3.793	2.222	74.717	.453	.557	.677	.827	.002		
100.0	2	140113.	.152	0.000		3.079	3.786	2.221	74.637	.452	.556	.677	.826	.002		
100.0	3	140093.	.145	0.000		3.365	3.895	2.261	75.747	.324	.566	.728	.833	.002		
100.0	4	139974.	.145	0.000		3.364	3.887	2.260	75.777	.322	.564	.729	.834	.002		
100.0	5	140114.	.137	0.000		3.495	4.004	2.302	76.943	.299	.574	.743	.841	.002		
100.0	6	140099.	.136	0.000		3.492	4.005	2.299	77.005	.301	.575	.742	.840	.002		
100.0	7	139941.	.133	0.000		3.532	4.054	2.317	77.503	.301	.578	.745	.844	.002		
100.0	8	139985.	.133	0.000		3.530	4.062	2.319	77.544	.305	.579	.744	.844	.002		
100.0	9	140054.	.126	0.000		3.586	4.143	2.344	78.417	.309	.587	.745	.845	.002		
100.0	10	139976.	.125	0.000		3.588	4.145	2.345	78.421	.309	.587	.745	.847	.002		
100.0	11	140137.	.120	0.000	.118	3.614	4.230	2.369	79.134	.331	.596	.739	.849	.002		
100.0	12	140157.	.120	0.000	.118	3.616	4.229	2.369	79.118	.330	.595	.740	.849	.002		
90.0	13	126218.	.128	0.000		1.563	3.048	1.958	74.225	1.362	.442	.306	.844	.003		
90.0	14	126083.	.128	0.000		1.546	3.043	1.956	74.221	1.377	.441	.299	.844	.003		
90.0	15	126128.	.123	0.000		2.732	3.126	1.976	75.255	.342	.453	.731	.845	.003		
90.0	16	126245.	.124	0.000		2.731	3.119	1.975	75.141	.339	.452	.732	.845	.003		
90.0	17	126173.	.112	0.000		2.890	3.227	2.014	76.998	.278	.464	.760	.853	.003		
90.0	18	126102.	.111	0.000		2.893	3.237	2.015	77.138	.282	.465	.759	.853	.003		
90.0	19	126091.	.102	0.000		2.949	3.308	2.039	78.454	.283	.473	.761	.856	.003		
90.0	20	126092.	.102	0.000		2.950	3.310	2.040	78.462	.284	.473	.761	.857	.003		
90.0	21	126052.	.097	0.000	.094	2.962	3.350	2.048	79.196	.298	.479	.756	.857	.003		
90.0	22	125973.	.097	0.000	.094	2.962	3.363	2.049	79.240	.305	.481	.753	.857	.003		
90.0	23	126126.	.126	0.000		2.572	3.088	1.956	74.674	.456	.451	.685	.840	.003		
90.0	24	126193.	.127	0.000		2.571	3.089	1.957	74.597	.458	.451	.684	.840	.003		
80.0	25	112098.	.107	0.000		1.389	2.476	1.719	73.733	1.437	.346	.284	.852	.003		
80.0	26	112143.	.109	0.000		1.388	2.479	1.719	73.629	1.436	.346	.283	.852	.003		
80.0	27	112147.	.104	0.000		2.219	2.515	1.732	74.512	.378	.352	.725	.855	.003		
80.0	28	112104.	.104	0.000		2.220	2.514	1.732	74.443	.376	.351	.726	.855	.003		
80.0	29	112003.	.094	0.000		2.371	2.593	1.761	76.547	.267	.362	.771	.862	.003		
80.0	30	112021.	.094	0.000		2.371	2.598	1.760	76.587	.270	.363	.768	.861	.003		
80.0	31	112035.	.085	0.000		2.431	2.658	1.780	78.219	.259	.372	.774	.863	.003		
80.0	32	111976.	.085	0.000		2.429	2.659	1.779	78.217	.261	.372	.773	.863	.003		
80.0	33	112045.	.078	0.000	.075	2.440	2.679	1.781	79.267	.266	.377	.767	.859	.003		
80.0	34	112040.	.078	0.000	.075	2.440	2.676	1.781	79.254	.264	.377	.766	.859	.003		
60.0	35	84104.	.077	0.000		1.158	1.721	1.359	72.225	1.552	.198	.216	.847	.004		
60.0	36	84044.	.077	0.000		1.157	1.718	1.359	72.142	1.557	.197	.216	.848	.004		
60.0	37	84035.	.072	0.000		1.505	1.714	1.368	72.960	.605	.193	.639	.859	.004		
60.0	38	84080.	.072	0.000		1.504	1.715	1.367	72.991	.608	.194	.636	.857	.004		
60.0	39	84083.	.068	0.000		1.582	1.727	1.377	74.004	.413	.195	.717	.864	.004		
60.0	40	84124.	.069	0.000		1.583	1.726	1.377	73.963	.411	.195	.718	.864	.004		
60.0	41	84130.	.061	0.000		1.658	1.760	1.390	76.224	.277	.201	.770	.869	.004		
60.0	42	84052.	.061	0.000		1.653	1.753	1.390	76.090	.263	.199	.778	.871	.004		
60.0	43	83958.	.054	0.000		1.693	1.785	1.399	78.087	.237	.206	.786	.871	.004		
60.0	44	84053.	.054	0.000		1.693	1.786	1.399	78.110	.240	.207	.783	.870	.004		
60.0	45	84337.	.044	0.000	.042	1.715	1.819	1.405	80.706	.250	.216	.771	.862	.004		
60.0	46	84304.	.044	0.000	.042	1.715	1.820	1.405	80.724	.254	.216	.770	.862	.004		
95.0	47	133148.	.140	0.000		1.620	3.322	2.090	74.080	1.381	.483	.305	.843	.002		
95.0	48	133113.	.139	0.000		1.620	3.339	2.089	74.232	1.376	.486	.302	.842	.002		
95.0	49	133189.	.136	0.000		2.958	3.449	2.101	75.131	.364	.504	.717	.837	.003		
95.0	50	133106.	.135	0.000		2.961	3.440	2.100	75.100	.358	.502	.720	.838	.003		
95.0	51	133163.	.128	0.000		3.136	3.567	2.142	75.470	.303	.516	.745	.845	.003		
95.0	52	133215.	.128	0.000		3.135	3.561	2.141	76.395	.300	.515	.746	.845	.003		
95.0	53	133111.	.118	0.000		3.218	3.645	2.168	77.738	.289	.523	.753	.849	.003		
95.0	54	132880.	.118	0.000		3.216	3.650	2.160	77.407	.292	.524	.752	.849	.003		
95.0	55	133220.	.107	0.000	.105	3.271	3.776	2.203	79.280	.321	.538	.744	.852	.003		
95.0	56	133230.	.107	0.000	.105	3.273	3.780	2.203	79.246	.321	.539	.744	.852	.003		
110.0	57	153974.	.168	0.000		2.117	4.354	2.438	74.492	1.107	.655	.362	.791	.002		
110.0	58	153941.	.168	0.000		2.118	4.330	2.437	74.816	1.159	.651	.364	.792	.002		
110.0	59	154437.	.159	0.000		3.921	4.683	2.521	76.039	.352	.687	.684	.800	.002		
110.0	60	154434.	.159	0.000		3.923	4.683	2.520	76.073	.351	.687	.684	.799	.002		
110.0	61	154352.	.151	0.000		4.134	4.869	2.598	76.933	.324	.694	.713	.815	.002		
110.0	62	154204.	.151	0.000		4.134	4.878	2.593	76.460	.326	.695	.713	.815	.002		
110.0	63	154301.	.157	0.000		4.228	5.012	2.642	77.539	.331	.704	.718	.823	.002		
110.0	64	154045.	.157	0.000		4.227	5.006	2.640	77.539	.327	.702	.719	.824	.002		
110.0	65	154231.	.168	0.000		3.530	4.492	2.439	75.232	.409	.677	.635	.764	.002		
110.0	66	154080.	.168	0.000		3.529	4.479	2.439	75.276	.406	.674	.637	.765	.002		
105.0	67	147241.	.161	0.000		1.984	4.051	2.351	74.675	1.216	.597	.359	.816	.002		
105.0	68	147115.	.161	0.000		1.990	4.050	2.349	74.620	1.217	.597	.359	.817	.002		
105.0	69	147065.	.161	0.000		3.161	4.164	2.345	75.073	.363	.616	.623	.810	.002		
105.0	70	147030.	.161	0.000		3.160	4.173	2.347	75.113	.366	.617	.622	.811	.002		
105.0	71	147251.	.155	0.000		3.673	4.310	2.405	76.073	.335	.625	.714	.821	.002		
105.0	72	147154.	.154	0.000		3.675	4.326	2.405	76.155	.339	.628	.712	.821	.002		
105.0	73	147050.	.147	0.000		3.846	4.495	2.468	77.350	.320	.638	.730	.833	.002		
105.0	74	147041.	.146	0.000		3.841	4.483	2.466	77.353	.318	.637	.730	.833	.002		
105.0	75	146931.	.143	0.000		3.924	4.605	2.511	78.244	.323	.644	.736	.841	.002		
105.0	76	146993.	.139	0.000		3.926	4.609	2.511	78.355	.326	.645	.734	.841	.002		

MERDC 3K4 COMPRESSOR   VANED DIFFUSER   CLOSE AXIAL CLEARANCES TEST 3A
P1-ORIF. P2   P2-INLET HUB PS   P3-INLET SHRD PS
P4-IMP. BACKFACE PS
P5-DIFF THROAT PS   P6-COLLECTOR PS   T1-COLLECTOR METAL T
CLEARANCE PLANE 1 - AXIAL   CLEARANCE PLANE 2 - RADIAL
IMPELLER P/N 3604188-1 S/N 2, SHROUD P/N 3604223-1
INLET HOUSING P/N 3604225-1. COLLECTOR P/N 360422
VANED DIFFUSER P/N 3604748-1
CAPACITANCE CALIBRATION - Y465
TEST DATE - SEPTEMBER 23, 1975

INDUCER TIP DIAMETER	1.360400	0.000000
INDUCER HUB DIAMETER	.855000	0.000000
INLET BLOCKAGE	.980000	0.000000
WHEEL TIP DIAMETER	2.525000	0.000000
STATIC TAP LOCATION	2.525001	0.000000
DIFFUSER WIDTH	.078000	0.000000
DIFFUSER BLOCKAGE	.900000	0.000000
DIFFUSION COEFFICIENT	-0.000000	0.050000
BLADE ANGLE	37.450000	0.000000

GRAVITATIONAL CONSTANT	=	32.1740
GAS CONSTANT	=	53.3450
TEMPERATURE CONVERSION	=	1000.0000
DELTA P CONVERSION	=	100.0000
SPEED CONVERSION	=	10.0000
CLEARANCE CONVERSION	=	10000.0000
DUCT DIAMETER	=	2.0670

PO2-INLET TOTAL PRESSURE
PO3-STAGE EXIT TOTAL PRESSURE
PO4-NOT APPLICABLE
PS2.5-IMPELLER EXIT STATIC PRESSURE
PS3-DIFFUSER EXIT STATIC PRESSURE
PS3.5-NOT APPLICABLE
PS4-NOT APPLICABLE
PS( )-NOT APPLICABLE
P6 THROUGH P17-NOT APPLICABLE

TO1-NOT APPLICABLE
TO2-INLET TOTAL TEMPERATURE
TO3-EXIT TOTAL TEMPERATURE
TO4-NOT APPLICABLE
TO5-ORIFICE TEMPERATURE
TREF-REFERENCE TEMPERATURE
T2 THROUGH T6-NOT APPLICABLE

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS,AVERAGES,AND PRESSURE RATIOS

P02	P03	P04	PS2.5	PS3	PS3.5	PS4	PS(H)	P1	P2	P3	P4	P5
28.850	0.000	0.000	70.564	97.582	0.000	0.000	0.000	28.105	28.567	28.242	57.687	78.075
28.850	0.000	0.000	70.650	96.955	0.000	0.000	0.000	28.085	28.567	28.222	0.000	78.544
28.850	102.034	0.000	63.340	97.198	0.000	0.000	0.000	0.000	28.567	28.222	0.000	81.123
28.850	99.623	0.000	62.341	97.582	0.000	0.000	0.000	0.000	28.567	28.222	0.000	81.021
28.850	102.665	0.000	64.545	97.481	0.000	0.000	0.000	0.000	0.000	0.000	0.000	80.352
28.850	102.686	0.000	63.911	97.663	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	99.472	0.000	66.809	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	98.613	0.000	68.911	97.157	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	101.977	0.000	67.503	97.744	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	98.635	0.000	65.115	97.441	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	97.643	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	99.162	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	99.465	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.625	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.904	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	101.625	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	97.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	98.419	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28.850	100.823	0.000	66.403	97.447	0.000	0.000	0.000	28.095	28.567	28.227	57.687	79.823

P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
97.925	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
97.347	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
98.251	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29.735	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80.815	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

AERO 15W COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS, AVERAGES, AND PRESSURE RATIOS

P03/P	P13/P	P34/P	PS2.5/P	PS3/P	PS3.5/P	PS4/P	PS5/P	P1/P	P2/P	P3/P	P4/P	P5/P
1.0000	0.0000	0.0000	2.4459	3.3824	0.0000	0.0000	0.0000	.9742	.9902	.9789	1.9995	2.7062
1.0010	0.0000	0.0000	2.4558	3.3606	0.0000	0.0000	0.0000	.9735	.9902	.9782	0.0000	2.7225
1.0001	3.5164	0.0000	2.1955	3.3631	0.0000	0.0000	0.0000	0.0000	.9902	.9782	0.0000	2.8119
1.0010	3.4533	0.0000	2.1622	3.3824	0.0000	0.0000	0.0000	0.0000	.9902	.9782	0.0000	2.6084
1.0010	3.4583	0.0000	2.2404	3.3789	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.7651
1.0011	3.4573	0.0000	2.2143	3.3852	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4652	0.0000	2.3157	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4252	0.0000	2.3486	3.3677	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5347	0.0000	2.3398	3.3880	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4187	0.0000	2.2370	3.3782	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0000	0.0000	0.0000	0.0000	3.3345	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0010	3.5452	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4371	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4477	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4572	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4670	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.[illegible]17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4343	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.[illegible]	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4257	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.[illegible]	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0000	3.4947	0.0000	2.3017	3.3777	0.0000	0.0000	0.0000	.9738	.9902	.9784	1.9995	2.7668

P6/P	P7/P	P8/P	P9/P	P10/P	P11/P	P12/P	P13/P	P14/P	P15/P	P16/P	P17/P
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.3903	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.3930	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.4055	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.8012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS.AVERAGES.AND TEMPERATURE RATIOS

T01	T02	T03	T04	T05	T REF.	T1	T2	T3	T4	T5	T6
0.000	525.926	827.927	0.000	738.128	490.890	815.987	0.000	0.000	0.000	0.000	0.000
0.000	525.374	826.261	0.000	738.173	610.088	812.831	0.000	0.000	0.000	0.000	0.000
0.000	0.000	831.699	0.000	0.000	491.579	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	831.304	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	527.134	828.467	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	526.463	829.818	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	828.918	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	831.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	827.072	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	825.540	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	826.841	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	526.474	828.647	0.000	738.151		814.409	0.000	0.000	0.000	0.000	0.000

T01/T	T02/T	T03/T	T04/T	T05/T	T REF./T	T1/T	T2/T	T3/T	T4/T	T5/T	T6/T
0.0000	.9990	1.5726	0.0000	1.4020	.9324	1.5499	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	.9998	1.5694	0.0000	1.4021	1.1588	1.5439	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5801	0.0000	0.0000	.9337	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5790	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0013	1.5736	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0000	1.5762	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5745	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5795	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5710	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5691	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5765	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0000	1.5740	0.0000	1.4021		1.5469	0.0000	0.0000	0.0000	0.0000	0.0000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

REFERENCE PRESSURES

	-15 HG	-50 H2O	0 REF.	5 HG	50 HG	100 HG	150 HG	200 HG	300 HG
	-9.9550	-3.6665	0.0000	5.0000	50.0000	100.0000	150.0000	200.0000	300.0000
SCANNIVALVE 1	-9.8542	-3.7055	-.0204	4.9678	49.8616	99.7436	149.6256	199.5076	299.2715
SCANNIVALVE 2	-15.0053	-3.6643	.0407	4.9678	49.8616	100.0287	150.1957	200.3626	300.6968
SCANNIVALVE 3	-15.0053	-3.6643	.0514	5.0696	50.0856	100.3544	150.5626	200.7292	301.0226
SCANNIVALVE 4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SCANNIVALVE 5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SCANNIVALVE 6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

CLEARANCE PROBE DATA AND AVERAGES

PLANE 1(IN)	PLANE 2(IN)	PLANE 3(V)	PLANE 4(V)	PLANE 5(V)	PLANE 6(V)
.004	.003	0.000	0.000	0.000	0.000
.003	.005	0.000	0.000	0.000	0.000
.002	.004	0.000	0.000	0.000	0.000
.002	.006	0.000	0.000	0.000	0.000
.002	.005	0.000	0.000	0.000	0.000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

OVERALL AND STAGE PERFORMANCE PARAMETERS

	OVERALL	FIRST STAGE	SECOND STAGE
BELLMOUTH CORRECTED AIRFLOW =	0.000000		0.000000
BELLMOUTH PRESSURE RATIO =	1.000000		
BELLMOUTH SURGE =	0.000000		0.000000
ORIFICE CORRECTED AIRFLOW =	.137070		0.000000
ORIFICE SURGE =	0.000000		0.000000
SPEED RATIO =	1.000814		0.000000
CORRECTED SPEED =	140114.		0.
PRESSURE RATIO =	0.000000	3.494702	0.000000
STANDARD TEMPERATURE RISE =	0.000000	.574303	0.000000
CORR.ENTHALPY RISE, BTU/LB =	0.000000	71.919141	0.000000
ENTHALPY EFFICIENCY =	0.000000	.743231	0.000000

ORIFICE/ IN P=30.420 DEL P= 2.301 DIA= 1.250 FLOW COEF.= 0.000 THROAT DIA= 0.000 P01=28.850
BAROM.=28.850 HG.CALIB.= -9.955 H2O CALIB.= -3.666
TEST SWITCHES =-0.-0, 1.-0, 3, 1.-0.-0, 1, 1, 1, 1.-0,-0.-0, 5.-0.

VECTOR DIAGRAM AND INTERSTAGE PERFORMANCE PARAMETERS

	FIRST STAGE	SECOND STAGE
IMPELLER STATIC PRESSURE RATIO	2.301660	0.000000
IMPELLER TOTAL PRESSURE RATIO	4.004479	0.000000
IMPELLER ENTHALPY EFFICIENCY	.840715	0.000000
IMPELLER INLET ABSOLUTE MACH NUMBER	.281173	0.000000
IMPELLER TIP INLET RELATIVE ANGLE	69.464614	0.000000
IMPELLER EXIT MACH NUMBER	.927122	0.000000
IMPELLER EXIT FLOW COEFFICIENT	.175465	0.000000
IMPELLER EXIT RELATIVE ANGLE	54.240933	0.000000
IMPELLER EXIT SWIRL ANGLE	76.940291	0.000000
IMPELLER EXIT MOMENTUM LOSS	0.000000	0.000000
WORK COEFFICIENT (VU/J)	.755619	0.000000
IMPELLER ENTHALPY SLIP FACTOR (VU/U IDEAL)	.858046	0.000000
IMPELLER DEVIATION	16.790933	0.000000
STANDARD EULER DELTA T/T	.564606	0.000000
DIFFUSER EXIT MACH NUMBER	.220373	0.000000
DIFFUSER LOSS COEFFICIENT	.299372	0.000000
DIFFUSER ADIABATIC EFFICIENCY	.719398	0.000000
DIFFUSER RECOVERY	.631910	0.000000

MEHRC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 5
DATA BLOCK 5

	ORIFICE 1	ORIFICE 2	ORIFICE 3	ORIFICE 4		
P1	0.0000	0.0000	0.0000	0.0000	PS1	0.0000
DELTA P	0.0000	0.0000	0.0000	0.0000	PS2	0.0000
T1	0.0000	0.0000	0.0000	0.0000	DELTA PS/PS1	0.0000
FLOW	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 1	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 1/BELLMOUTH FLOW 1	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 2	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 2/BELLMOUTH FLOW 2	0.0000	0.0000	0.0000	0.0000		
ORIFICE FLOW	.1312					
ORIFICE CORR.AIRFLOW 1	.1371					
CORR.FLOW 1/BELLMOUTH FLOW 1	0.0000					
ORIFICE CORR.AIRFLOW 2	0.0000					
CORR.FLOW 2/BELLMOUTH FLOW 2	0.0000					

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS, AVERAGES, AND PRESSURE RATIOS

P02	P03	P04	PS2.5	PS3	PS3.5	PS4	PS(B)	P1	P2	P3	P4	P5
28.850	0.000	0.000	70.895	98.878	0.000	0.000	0.000	28.125	28.587	28.283	58.064	80.241
28.850	0.000	0.000	72.282	98.514	0.000	0.000	0.000	28.125	28.587	28.263	0.000	81.408
28.850	102.645	0.000	64.163	98.939	0.000	0.000	0.000	0.000	28.587	28.263	0.000	83.418
28.850	100.802	0.000	62.674	99.243	0.000	0.000	0.000	0.000	28.587	28.263	0.000	83.600
28.850	103.597	0.000	64.204	99.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	82.646
28.850	103.415	0.000	63.816	99.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	101.147	0.000	66.856	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.094	0.000	69.385	98.615	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.884	0.000	68.120	99.061	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.013	0.000	66.060	98.838	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	99.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	103.151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.499	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	103.678	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	103.617	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	102.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.539	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	100.215	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	103.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28.850	101.885	0.000	66.845	98.927	0.000	0.000	0.000	28.125	28.587	28.268	58.064	82.273

P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.243	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.587	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
99.648	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29.258	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
81.934	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS,AVERAGES,AND PRESSURE RATIOS

P02/P	P03/P	P04/P	PS2.5/P	PS3/P	PS3.5/P	PS4/P	PS/P	P1/P	P2/P	P3/P	P4/P	P5/P
1.0000	0.0000	0.0000	2.4573	3.4273	0.0000	0.0000	0.0000	.9749	.9909	.9803	2.0126	2.7831
1.0000	0.0000	0.0000	2.5054	3.4147	0.0000	0.0000	0.0000	.9749	.9909	.9796	0.0000	2.8218
1.0000	3.5579	0.0000	2.2240	3.4294	0.0000	0.0000	0.0000	0.0000	.9909	.9796	0.0000	2.8914
1.0000	3.4940	0.0000	2.1724	3.4400	0.0000	0.0000	0.0000	0.0000	.9909	.9796	0.0000	2.8977
1.0000	3.5409	0.0000	2.2254	3.4329	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	2.8647
1.0000	3.5846	0.0000	2.2120	3.4357	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5059	0.0000	2.3173	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4694	0.0000	2.4050	3.4182	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5663	0.0000	2.3612	3.4336	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4666	0.0000	2.2898	3.4259	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	3.4322	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5754	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4835	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4870	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5937	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5916	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5375	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4849	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.4736	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	3.5733	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0000	3.5315	0.0000	2.3170	3.4290	0.0000	0.0000	0.0000	.9749	.9909	.9798	2.0126	2.8517

P6/P	P7/P	P8/P	P9/P	P10/P	P11/P	P12/P	P13/P	P14/P	P15/P	P16/P	P17/P
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.4400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.4519	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3.4540	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2.8400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

DATA CONVERTED TO ABSOLUTE ENGINEERING UNITS,AVERAGES,AND TEMPERATURE RATIOS

T01	T02	T03	T04	T05	T REF.	T1	T2	T3	T4	T5	T6
0.000	526.239	829.458	0.000	739.337	490.936	818.286	0.000	0.000	0.000	0.000	0.000
0.000	526.463	828.062	0.000	739.024	610.061	813.688	0.000	0.000	0.000	0.000	0.000
0.000	0.000	833.869	0.000	0.000	491.579	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	834.769	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	527.134	831.394	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	526.776	833.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	830.854	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	833.374	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	829.458	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	828.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	829.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	526.653	831.046	0.000	739.180		815.987	0.000	0.000	0.000	0.000	0.000

T01/T	T02/T	T03/T	T04/T	T05/T	T REF./T	T1/T	T2/T	T3/T	T4/T	T5/T	T6/T
0.0000	.9492	1.5750	0.0000	1.4038	.9322	1.5537	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	.9996	1.5723	0.0000	1.4032	1.1583	1.5450	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5833	0.0000	0.0000	.9334	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5850	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0009	1.5786	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0002	1.5819	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5776	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5824	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5750	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5722	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	1.5744	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.0000	1.5780	0.0800	1.4635		1.5494	0.0000	0.0000	0.0000	0.0000	0.0000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

REFERENCE PRESSURES

	-15 HG	-50 H2O	0 REF.	5 HG	50 HG	100 HG	150 HG	200 HG	300 HG
	-9.9520	-3.6665	0.0000	5.0000	50.0000	100.0000	150.0000	200.0000	300.0000
SCANNIVALVE 1	-9.9542	-3.7055	-.0204	4.9678	49.8615	99.7436	149.6256	199.5076	299.2716
SCANNIVALVE 2	-15.0653	-3.6648	.0407	4.9678	49.8820	100.0287	150.1754	200.3220	300.6154
SCANNIVALVE 3	-15.0653	-3.6648	.0511	5.0493	50.0856	100.3544	150.5826	200.7292	301.0223
SCANNIVALVE 4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SCANNIVALVE 5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SCANNIVALVE 6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

CLEARANCE PROBE DATA AND AVERAGES

PLANE 1(IN)	PLANE 2(IN)	PLANE 3(V)	PLANE 4(V)	PLANE 5(V)	PLANE 6(V)
.002	.005	0.000	0.000	0.000	0.000
.003	.005	0.000	0.000	0.000	0.000
.002	.004	0.000	0.000	0.000	0.000
.002	.005	0.000	0.000	0.000	0.000
.002	.005	0.000	0.000	0.000	0.000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

OVERALL AND STAGE PERFORMANCE PARAMETERS

	OVERALL	FIRST STAGE	SECOND STAGE
BELLMOUTH CORRECTED AIRFLOW =	0.000000		0.000000
BELLMOUTH PRESSURE RATIO =	1.000000		0.000000
BELLMOUTH SURGE =	0.000000		0.000000
ORIFICE CORRECTED AIRFLOW =	.132785		0.000000
ORIFICE SURGE =	0.000000		0.000000
SPEED RATIO =	.999580		0.000000
CORRECTED SPEED =	139941.		0.
PRESSURE RATIO =	0.000000	3.531534	0.000000
STANDARD TEMPERATURE RISE =	0.000000	.578334	0.000000
CORR.ENTHALPY RISE, BTU/LB =	0.000000	72.429403	0.000000
ENTHALPY EFFICIENCY =	0.000000	.745354	0.000000

ORIFICE/ IN P=30.358 DEL P= 2.158 DIA= 1.250 FLOW COEF.= 0.000 THROAT DIA= 0.000 P01=28.850
BAROM.=28.850 HG.CALIB.= -9.955 H2O CALIB.= -3.665
TEST SWITCHES =-0,-0, 1,-0, 3, 1,-0,-0, 1, 1, 1, 1,-0,-0,-0, 5,-0,

VECTOR DIAGRAM AND INTERSTAGE PERFORMANCE PARAMETERS

	FIRST STAGE	SECOND STAGE
IMPELLER STATIC PRESSURE RATIO	2.316987	0.000000
IMPELLER TOTAL PRESSURE RATIO	4.053800	0.000000
IMPELLER ENTHALPY EFFICIENCY	.843702	0.000000
IMPELLER INLET ABSOLUTE MACH NUMBER	.271519	0.000000
IMPELLER TIP INLET RELATIVE ANGLE	70.081307	0.000000
IMPELLER EXIT MACH NUMBER	.932180	0.000000
IMPELLER EXIT FLOW COEFFICIENT	.169228	0.000000
IMPELLER EXIT RELATIVE ANGLE	54.417363	0.000000
IMPELLER EXIT SWIRL ANGLE	77.503457	0.000000
IMPELLER EXIT MOMENTUM LOSS	0.000000	0.000000
WORK COEFFICIENT (VU/U)	.762860	0.000000
IMPELLER ENTHALPY SLIP FACTOR (VU/U IDEAL)	.861130	0.000000
IMPELLER DEVIATION	16.967363	0.000000
STANDARD EULER DELTA T/T	.568320	0.000000
DIFFUSER EXIT MACH NUMBER	.204895	0.000000
DIFFUSER LOSS COEFFICIENT	.300704	0.000000
DIFFUSER ADIABATIC EFFICIENCY	.720897	0.000000
DIFFUSER RECOVERY	.640261	0.000000

MERDC 3KW COMPRESSOR VANED DIFFUSER CLOSE AXIAL CLEARANCES TEST 3A

UNIT 3 PCT SPD 100.00
TEST 3 SCAN 7
DATA BLOCK 7

	ORIFICE 1	ORIFICE 2	ORIFICE 3	ORIFICE 4		
P1	0.0000	0.0000	0.0000	0.0000	PS1	0.0000
DELTA P	0.0000	0.0000	0.0000	0.0000	PS2	0.0000
T1	0.0000	0.0000	0.0000	0.0000	DELTA PS/PS1	0.0000
FLOW	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 1	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 1/BELLMOUTH FLOW 1	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 2	0.0000	0.0000	0.0000	0.0000		
CORR.FLOW 2/BELLMOUTH FLOW 2	0.0000	0.0000	0.0000	0.0000		

ORIFICE FLOW	.1271
ORIFICE CORR.AIRFLOW 1	.1328
CORR.FLOW 1/BELLMOUTH FLOW 1	0.0000
ORIFICE CORR.AIRFLOW 2	0.0000
CORR.FLOW 2/BELLMOUTH FLOW 2	0.0000

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This report summarizes a study that performed the preliminary design of a small gas turbine engine, capable of providing 6-hp for driving a 1.5/3 Kw generator set, and presents the results of performance testing the resultant compressor design.